

L'espace poreux:

un monde à part...

Henri Vandamme,

Conférence inaugurale MATeB

10 juin 2013 Lyon

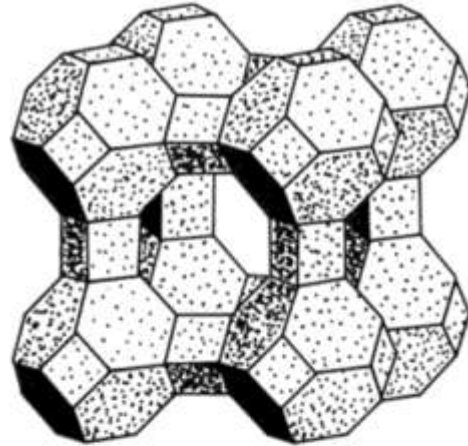




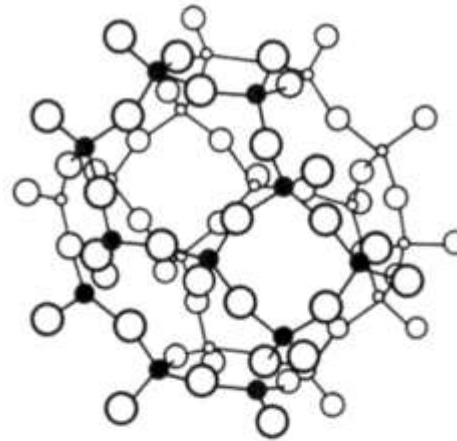
Des trous, oui mais lesquels ?



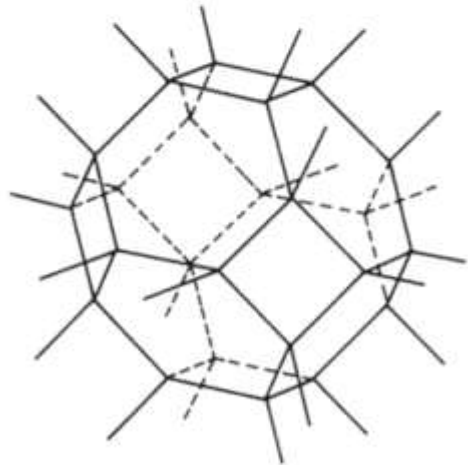




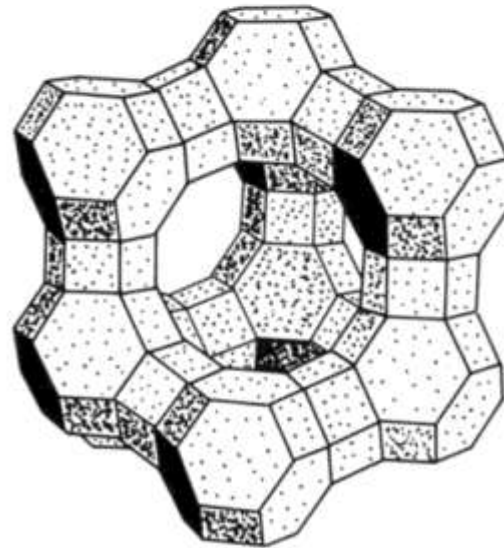
C



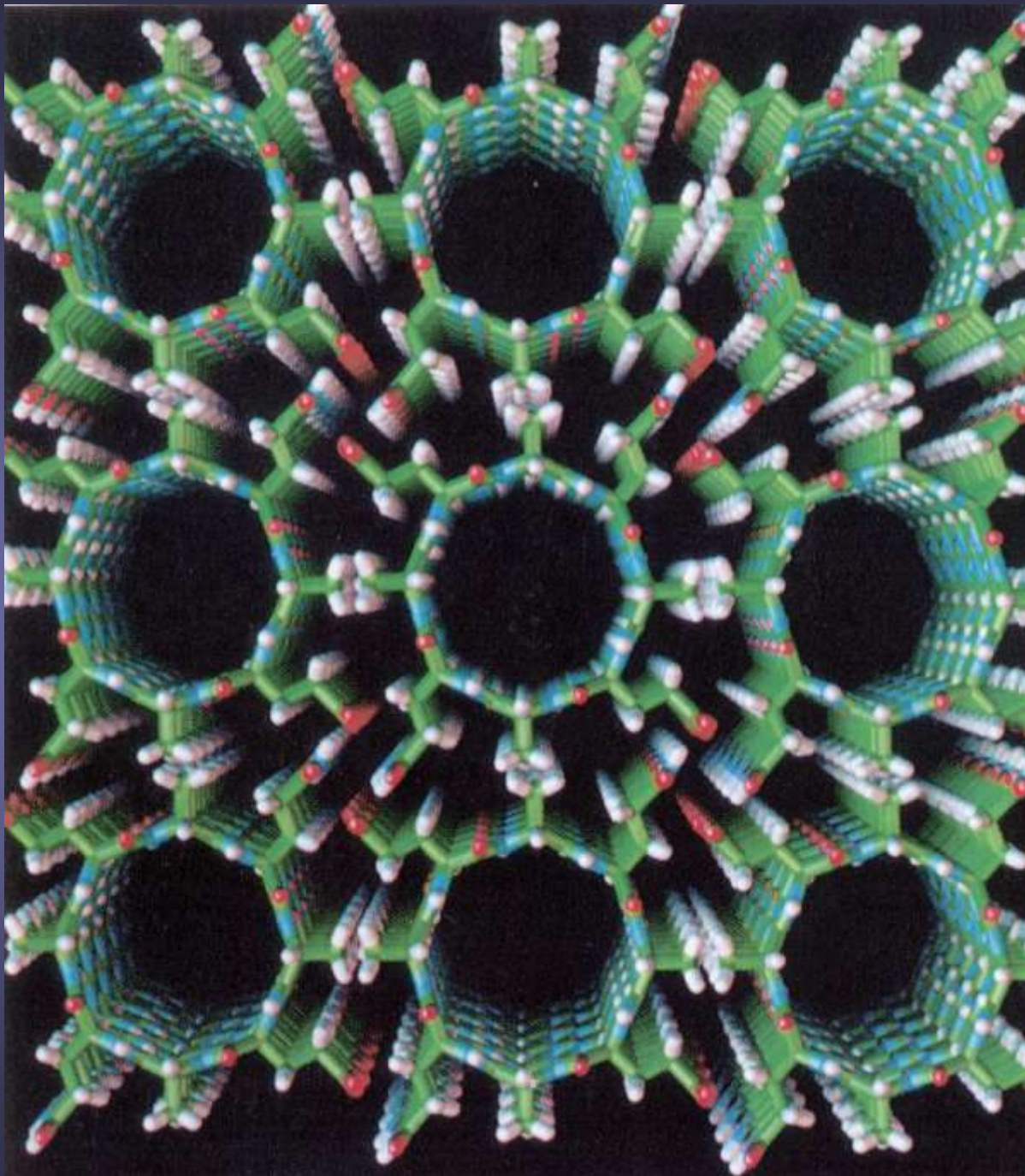
B



A



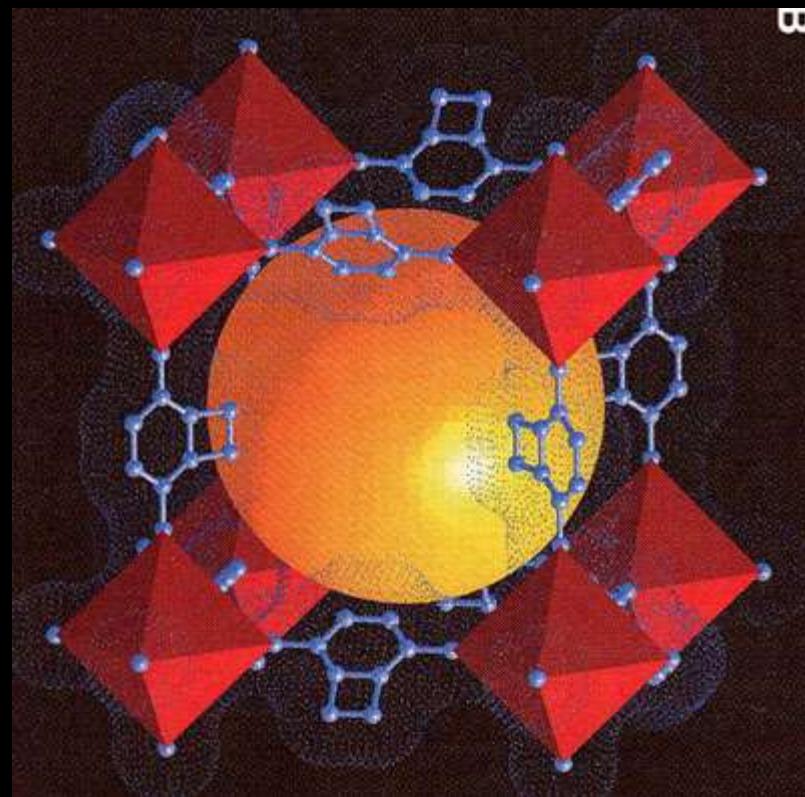
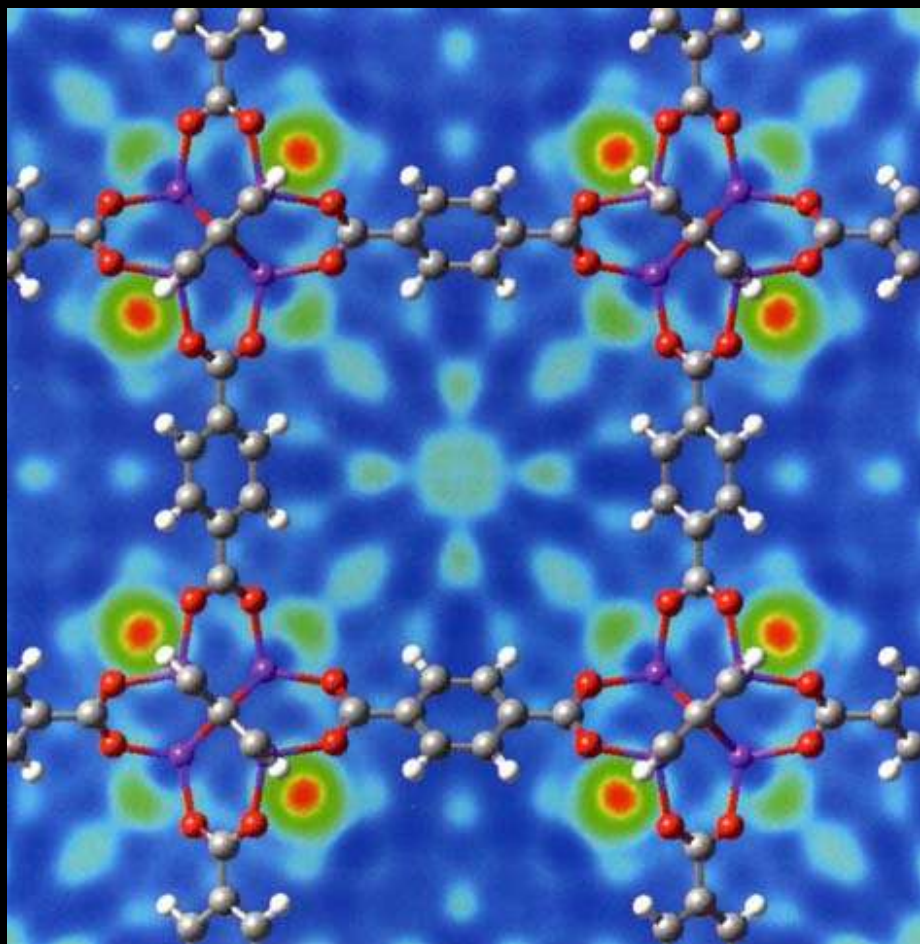
D



ZSM-5

M. Reza Ghadiri

MOF (Metal Oxide Framework)



$\phi = 0.775$; $240 \text{ cm}^3 \text{ CH}_4 \text{ STP/ g}$, à 36 atm et 298K

M. Eddaoudi et al., Science (2002)

Verre Vycor®

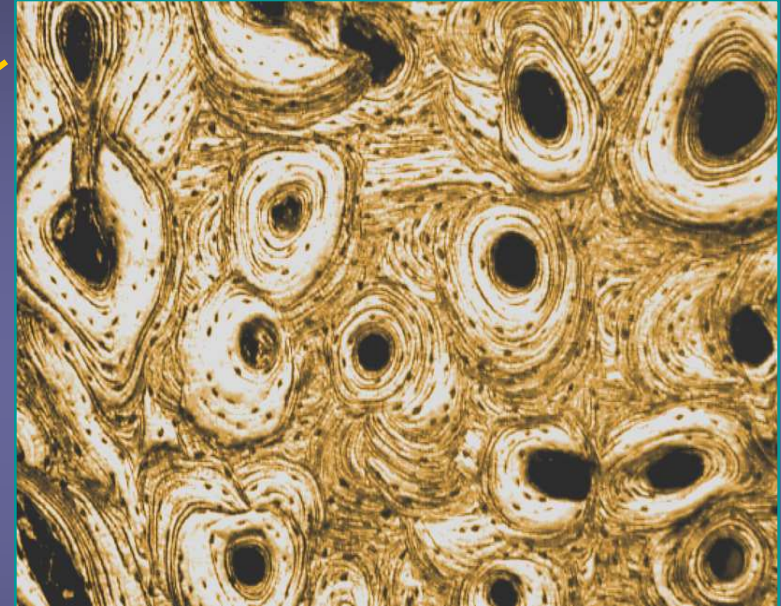
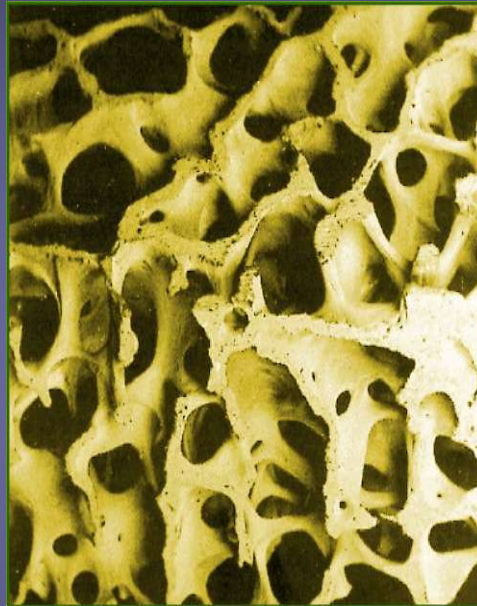
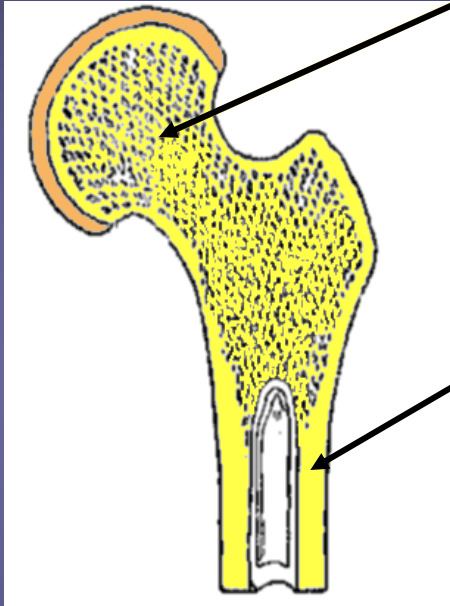


P. LEVITZ



Spongy bone ↓

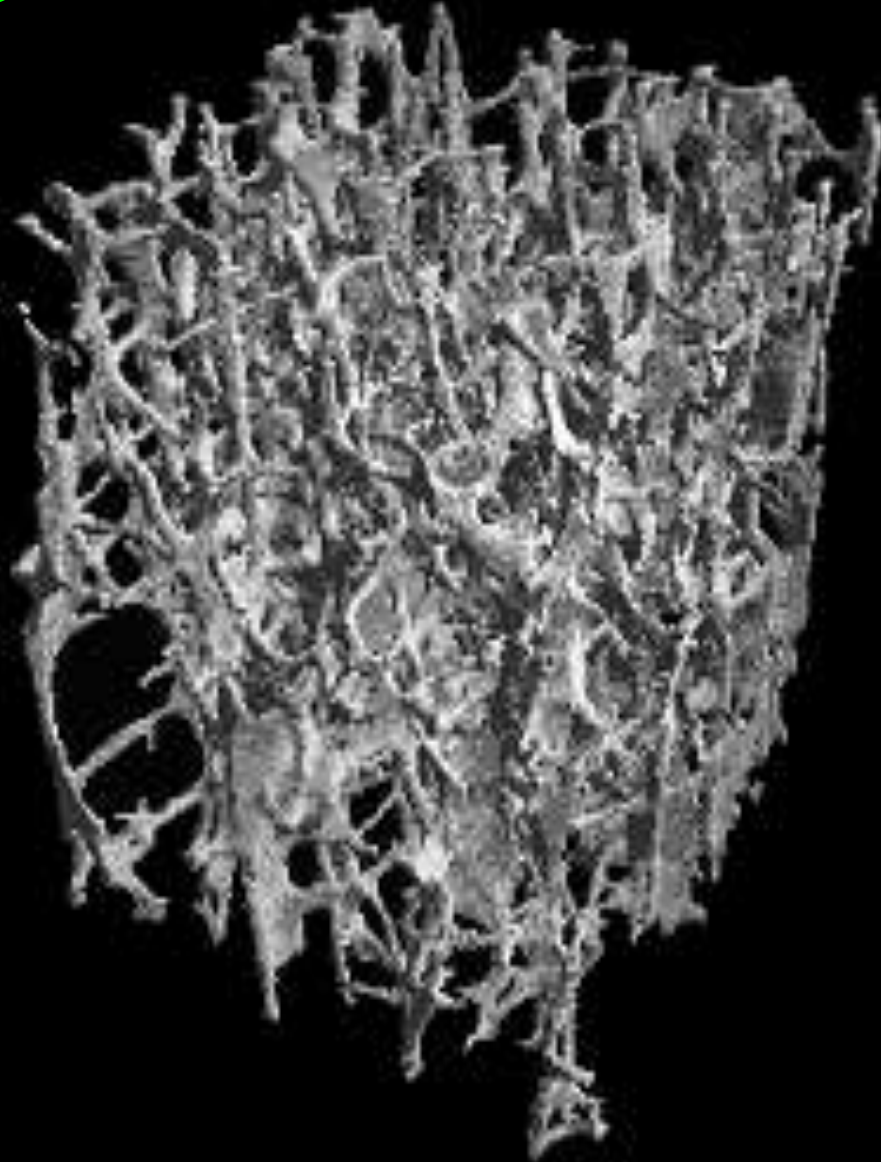
Cortical bone ↓



63 % mineral

37 % organic

Os trabéculaire



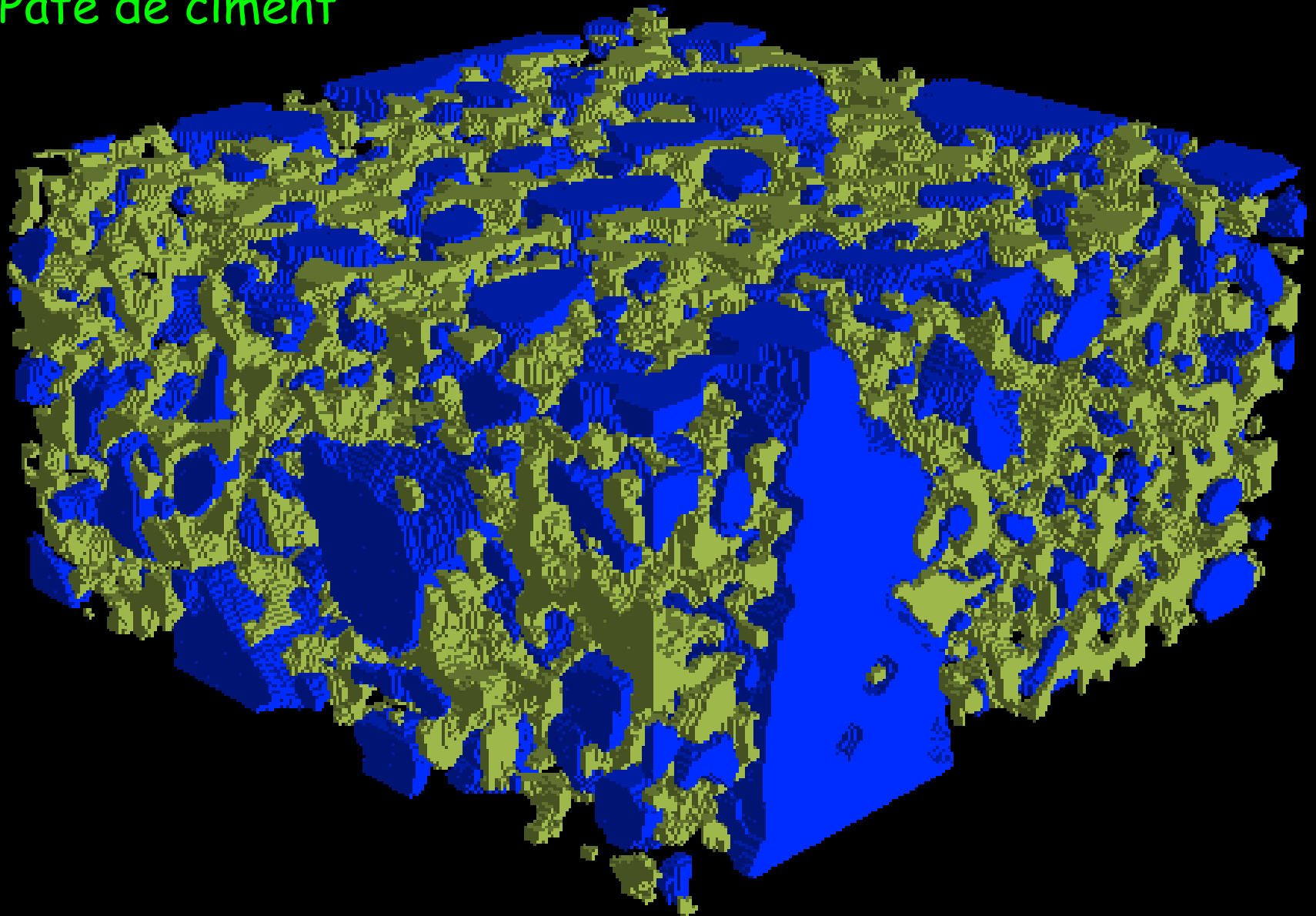
L. POTHUAUD & P. LEVITZ



Okinawa, National theater.

Shin Takamatsu Arch. & Assoc.

Pâte de ciment

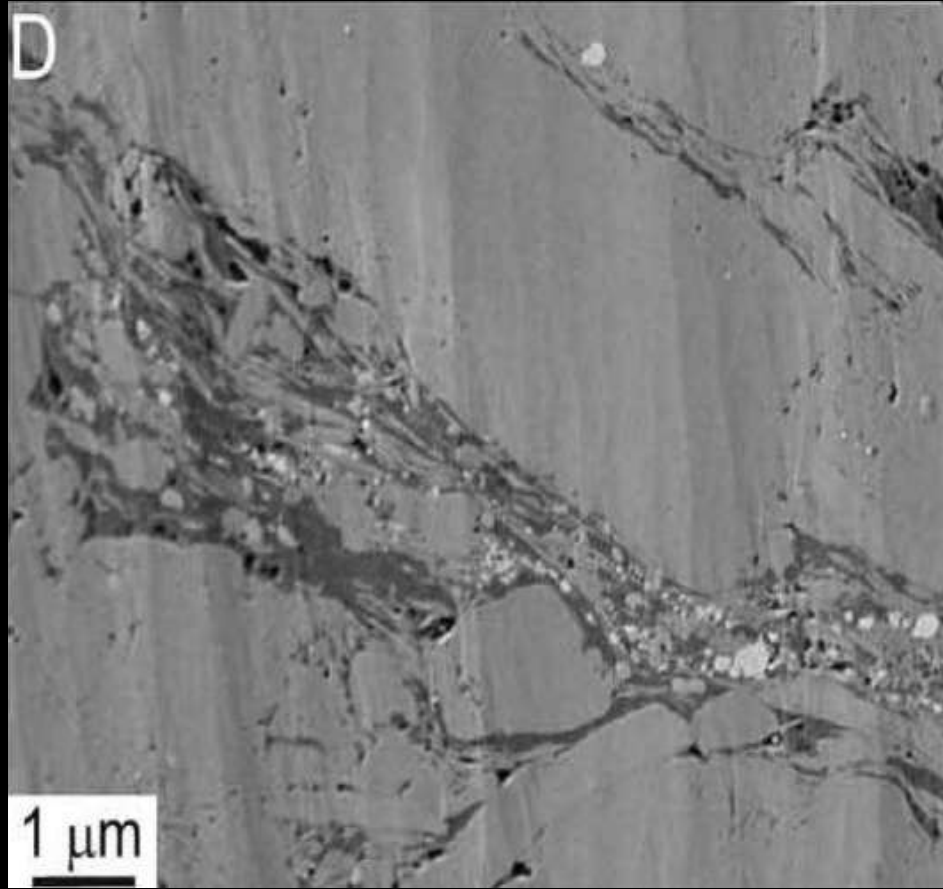
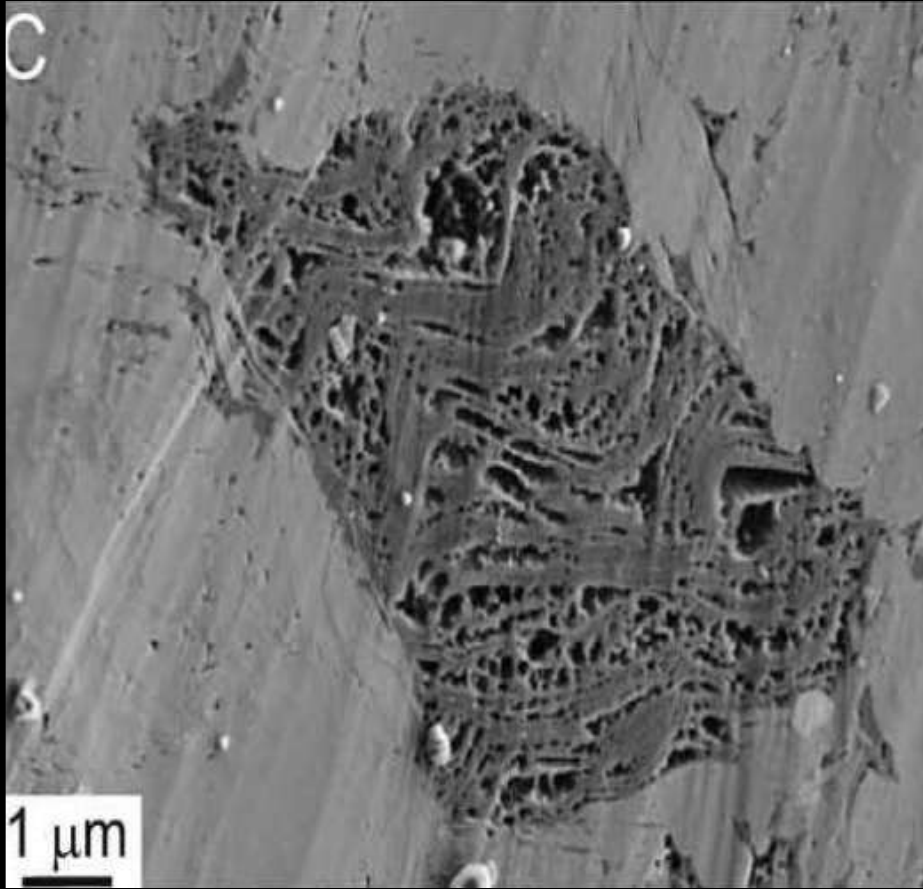


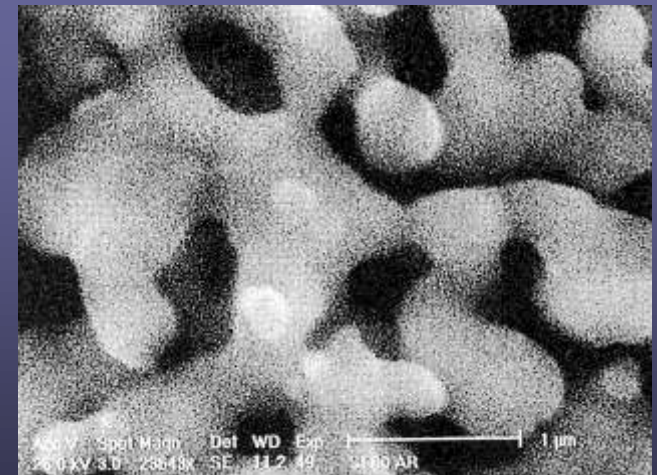
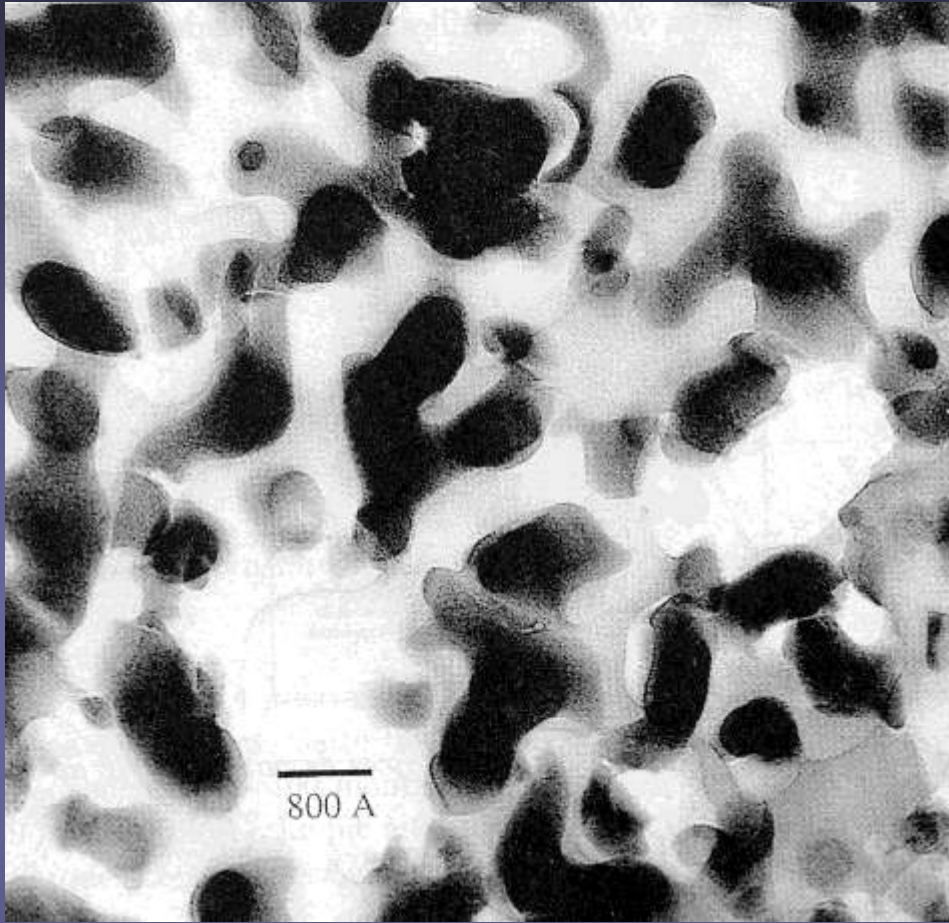
V. TARIEL & P. LEVITZ

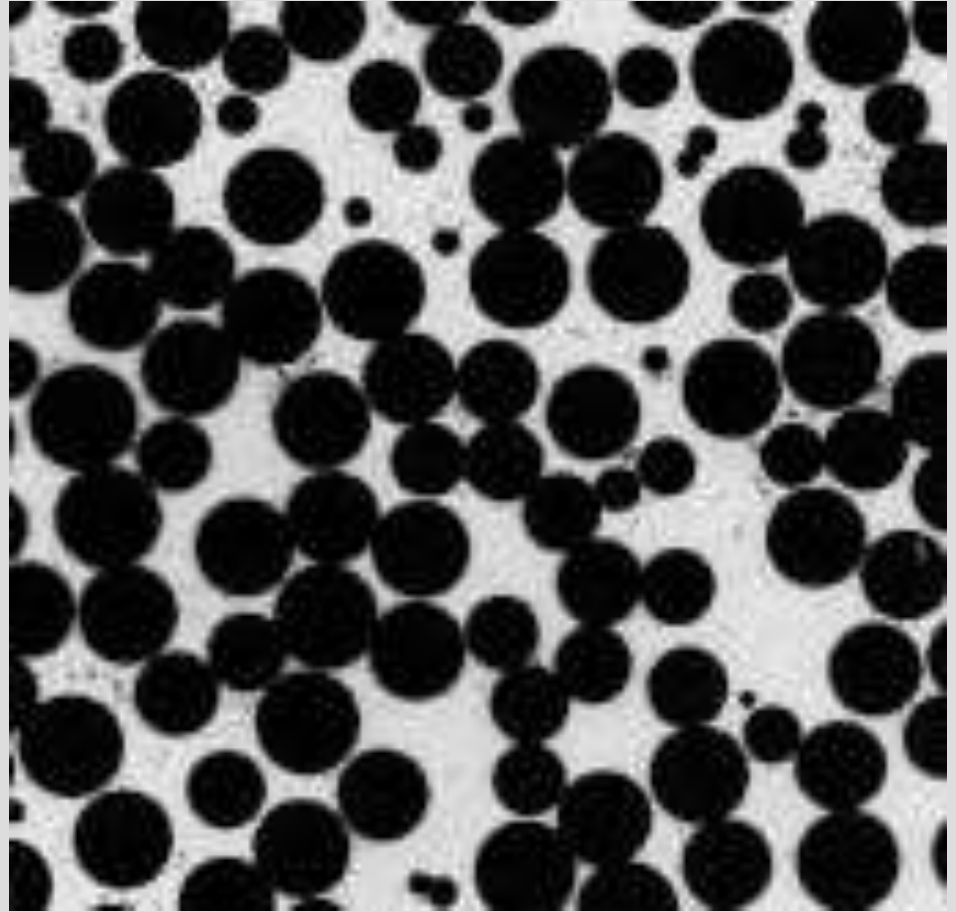
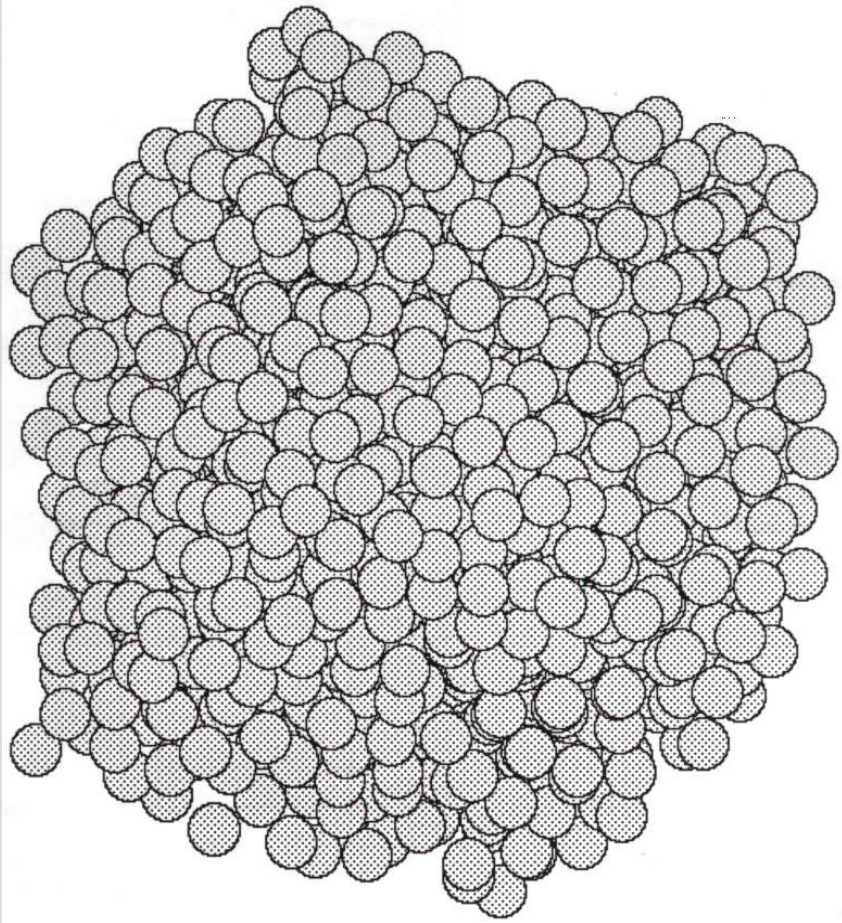
Le sol...

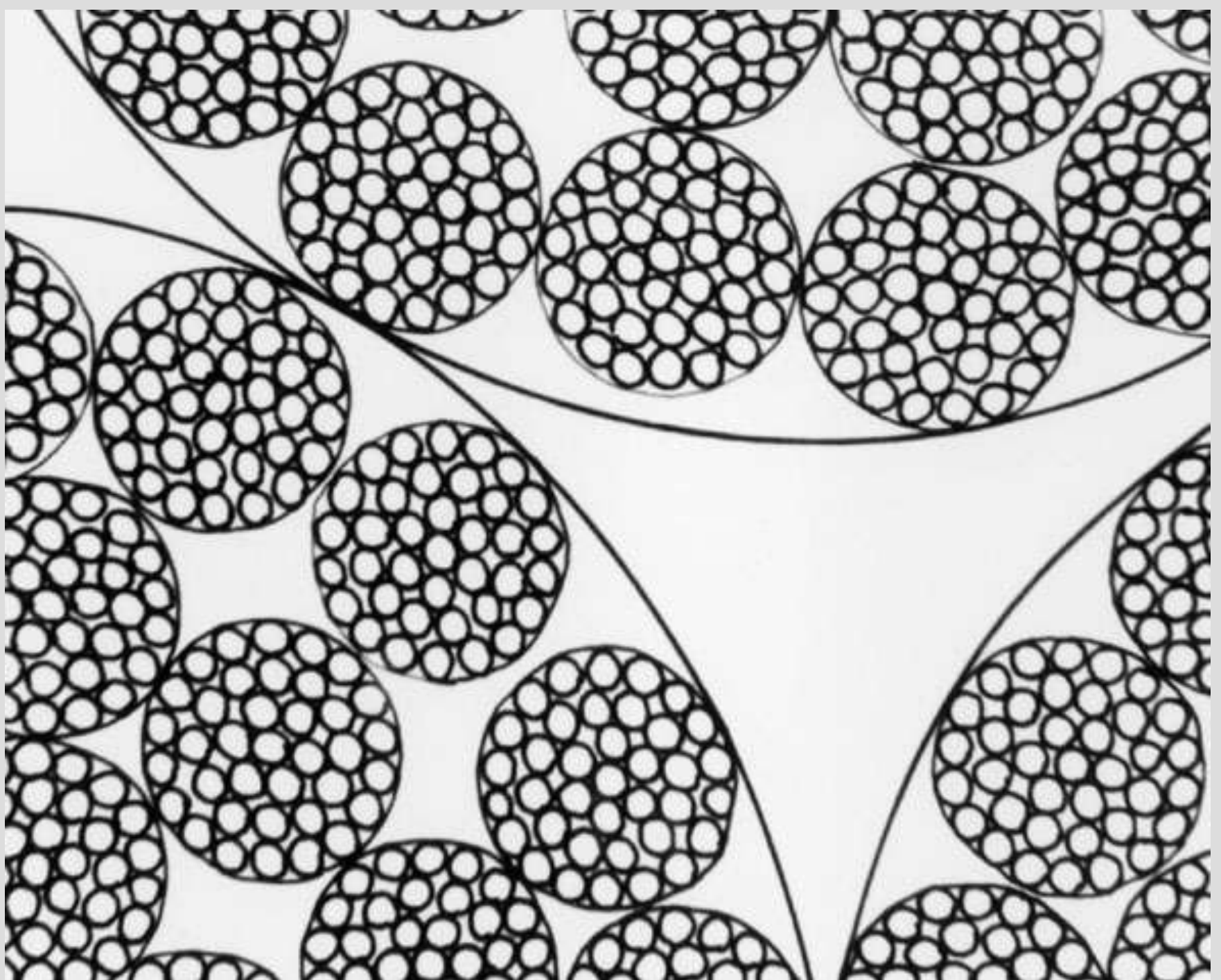


I. COUSIN & P. LEVITZ







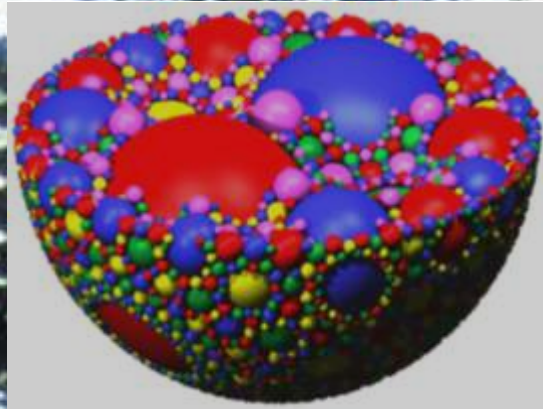




Ordonné ou désordonné ?...



« Mono- » ou « multiéchelle » ?...



MRS BULLETIN

November 2007, Volume 32, No. 11

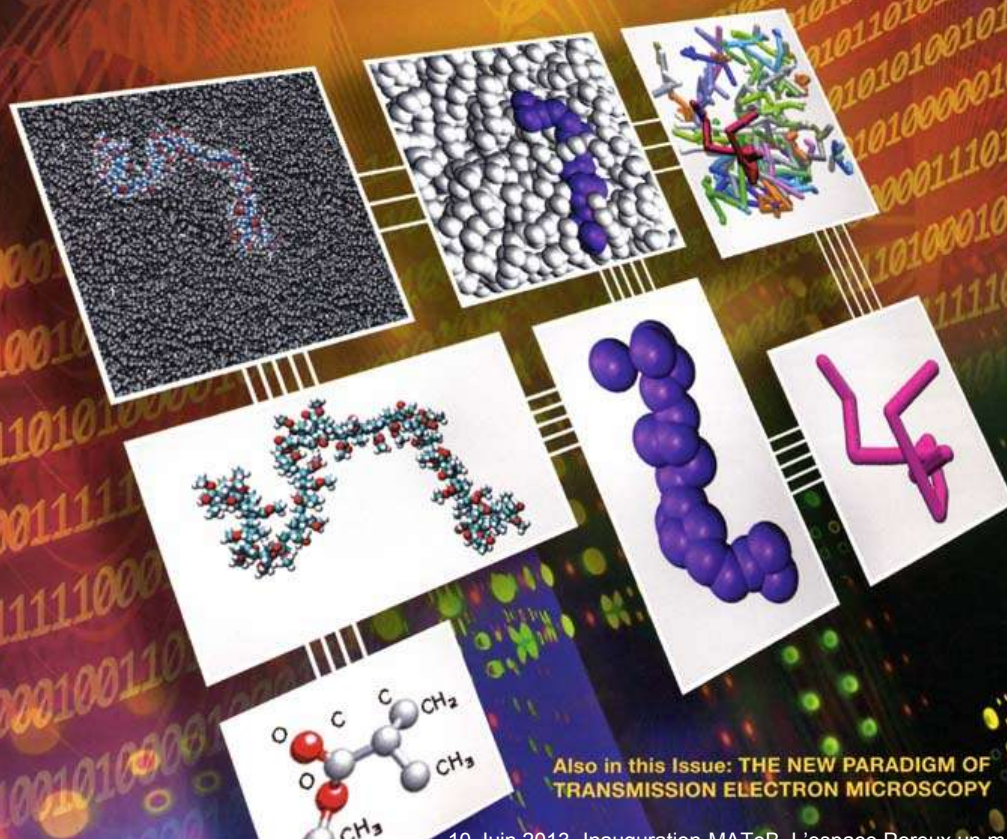
Serving the International
Materials Research Community

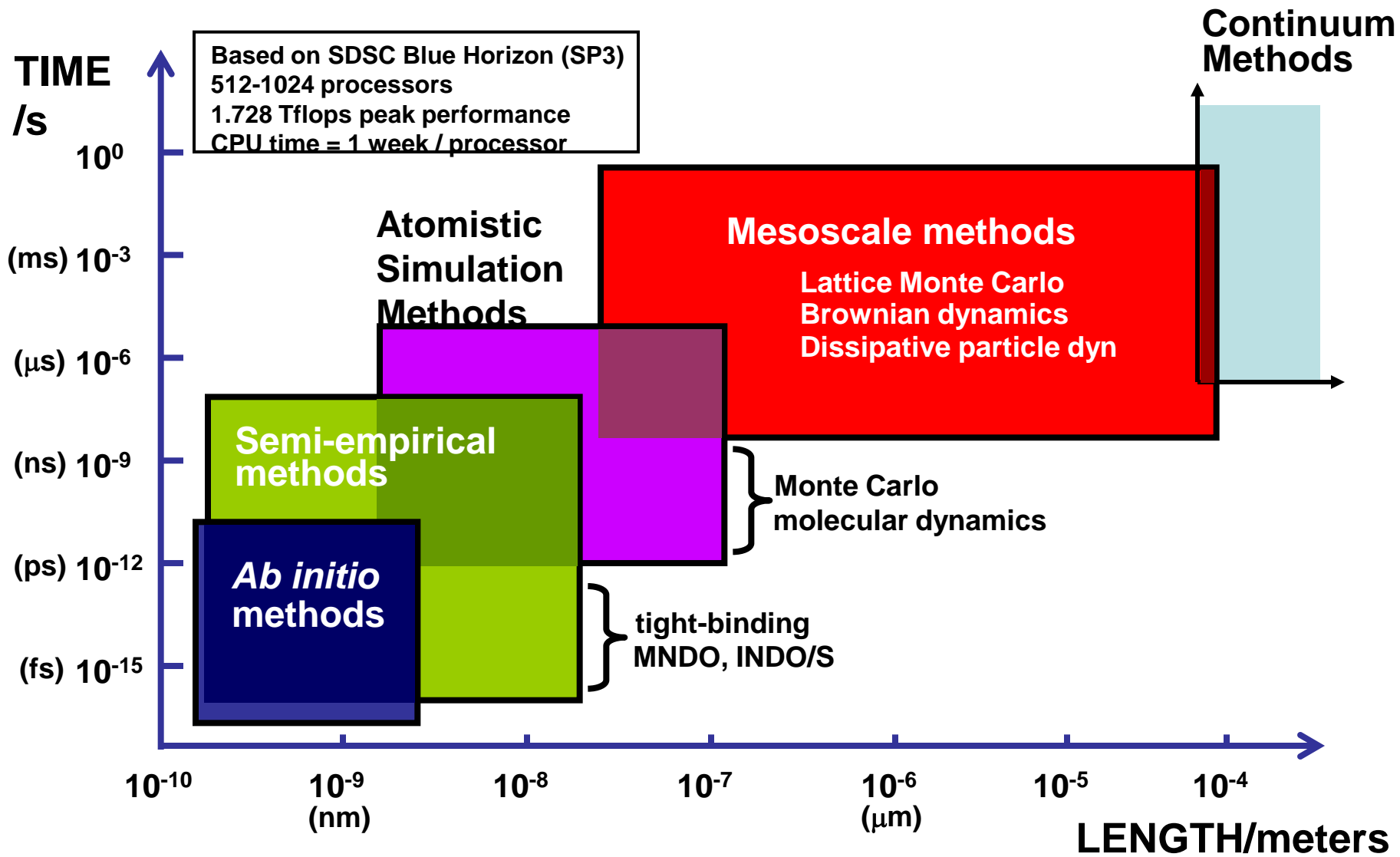
A Publication of the Materials Research Society



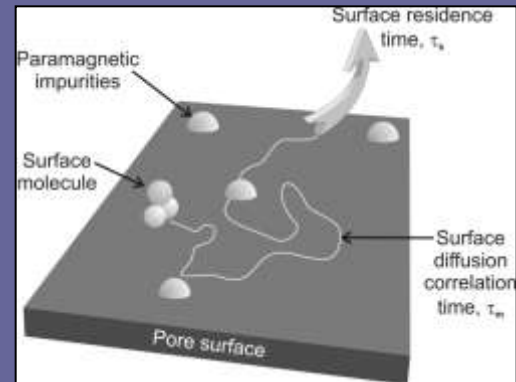
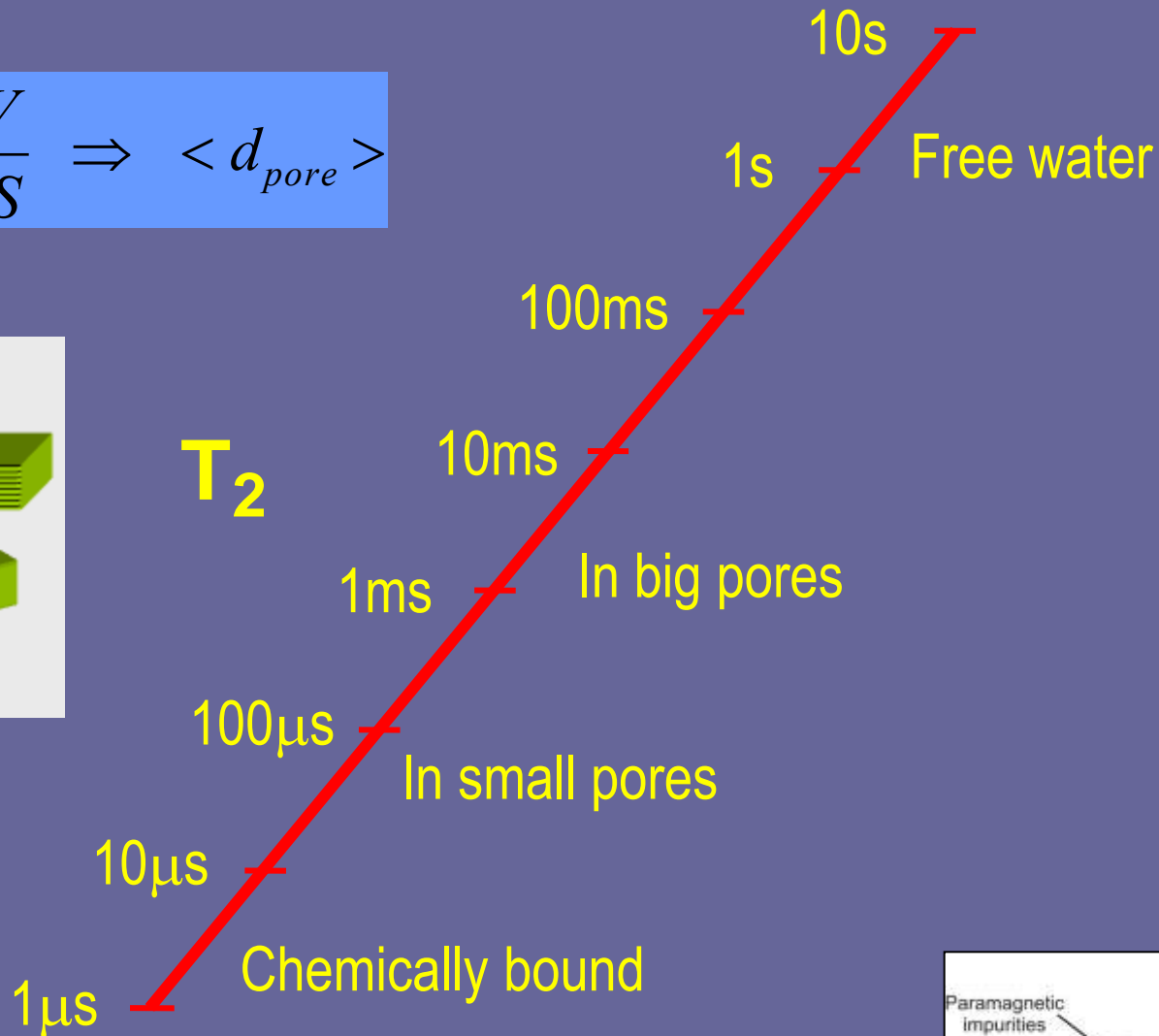
new!
InterFaces
Beyond the Lab
See page 166

Multiscale Modeling in Advanced Materials Research

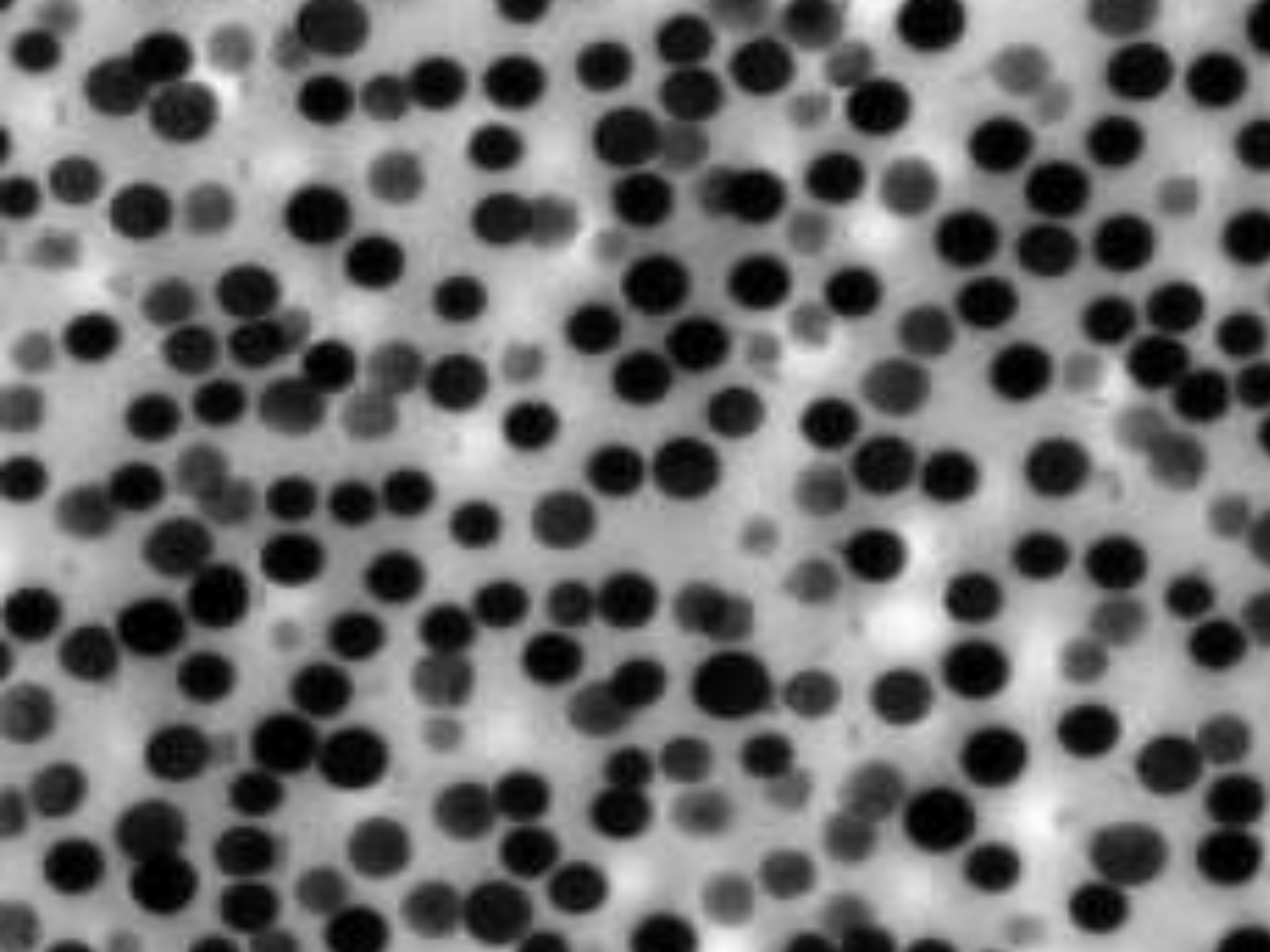




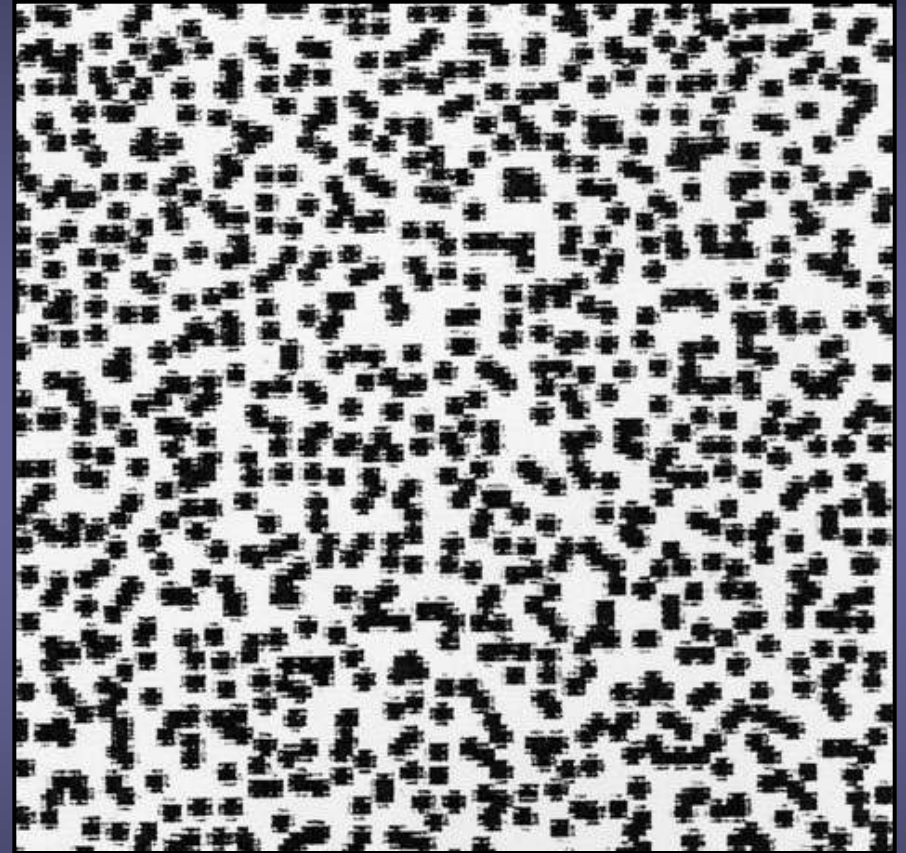
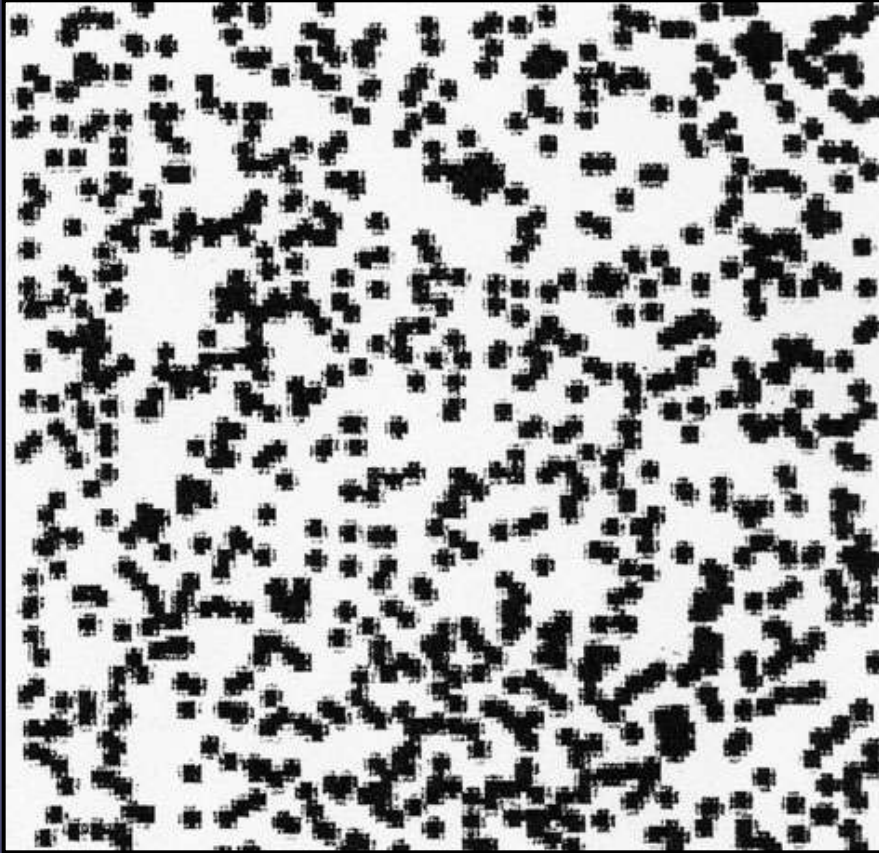
$$T_2 = \frac{T_{2,surf}}{\varepsilon} \frac{V}{S} \Rightarrow \langle d_{pore} \rangle$$



J-P Korb & D. Petit



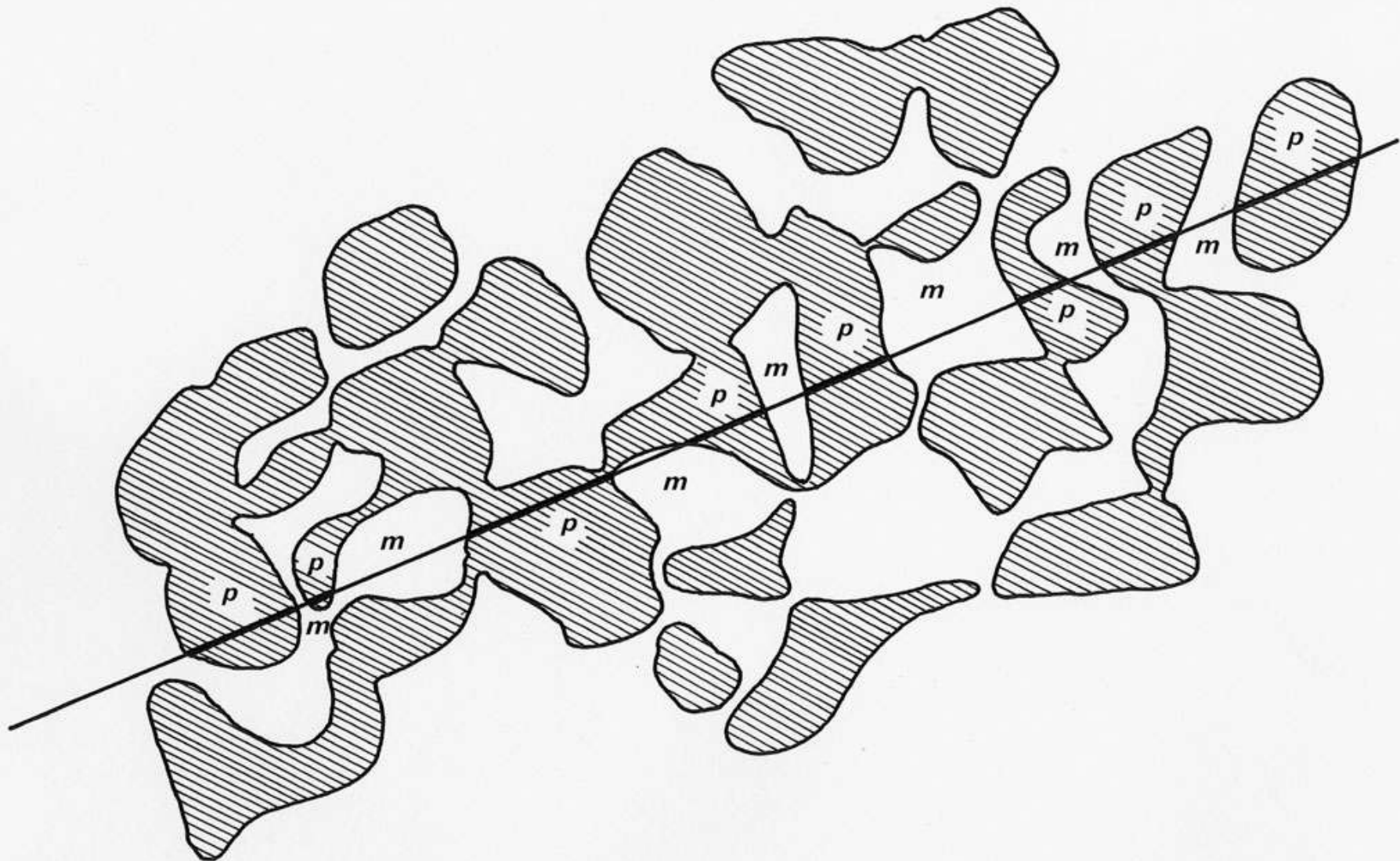




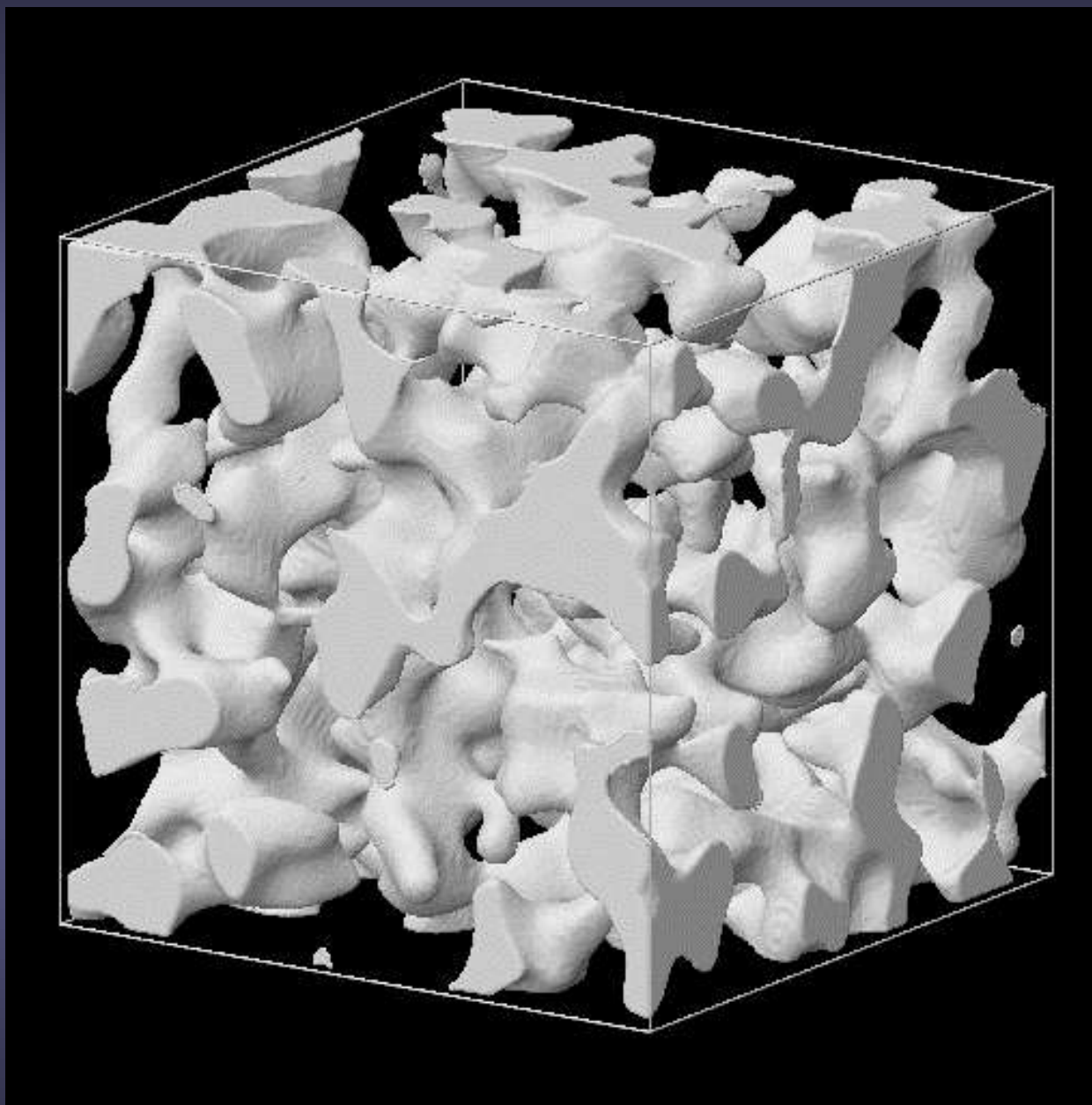


Nouakchott © Steinmetz

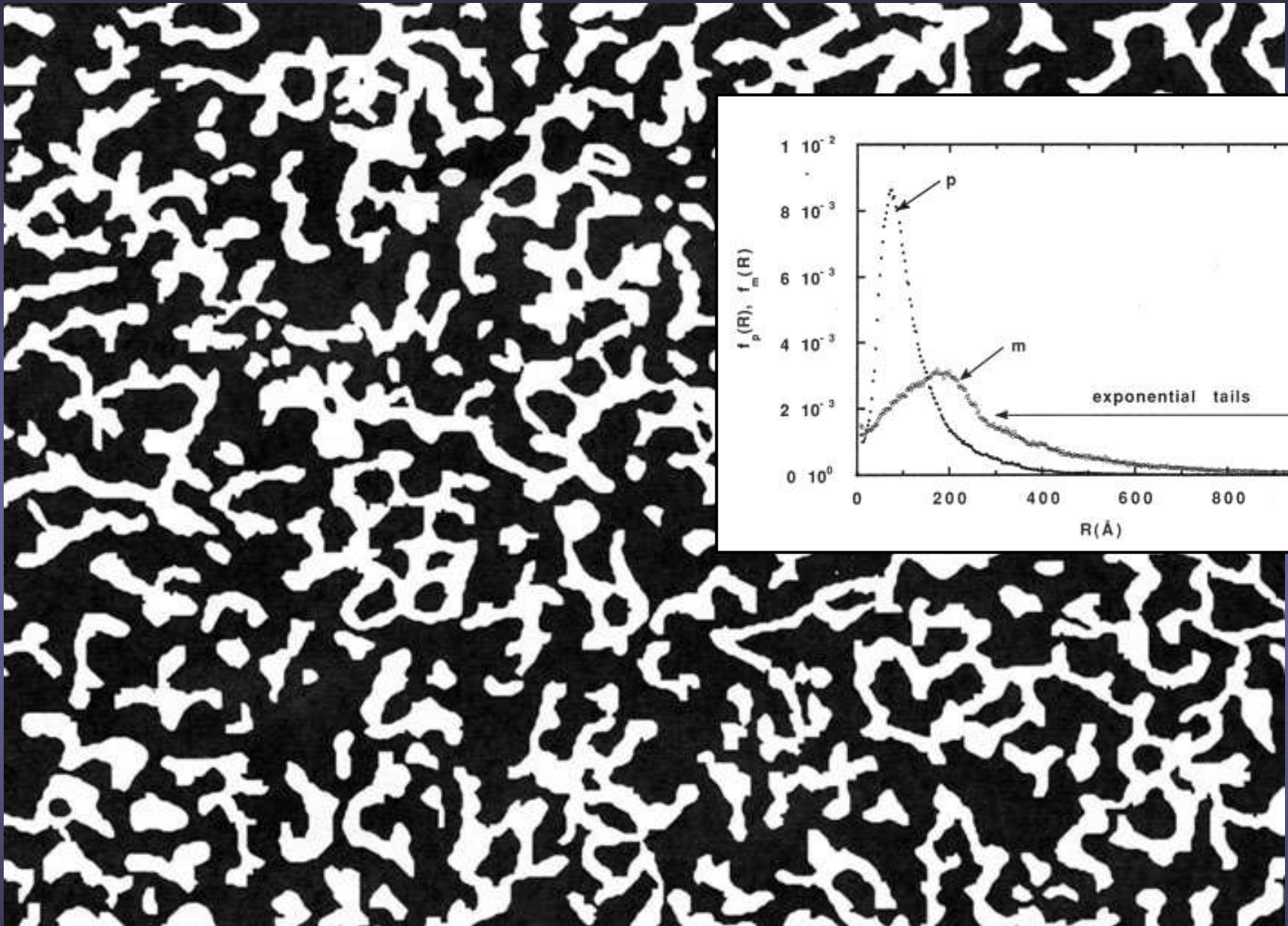
10 Juin 2013, Inauguration MATeB L'espace Poreux un monde à part, H. Vandamme



P. Levitz, D. Tchoubar



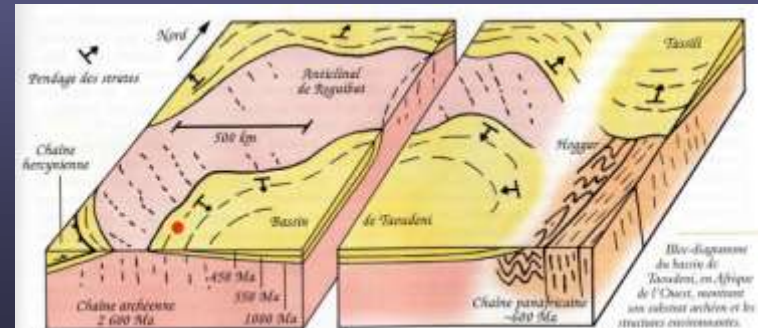
P. Levitz

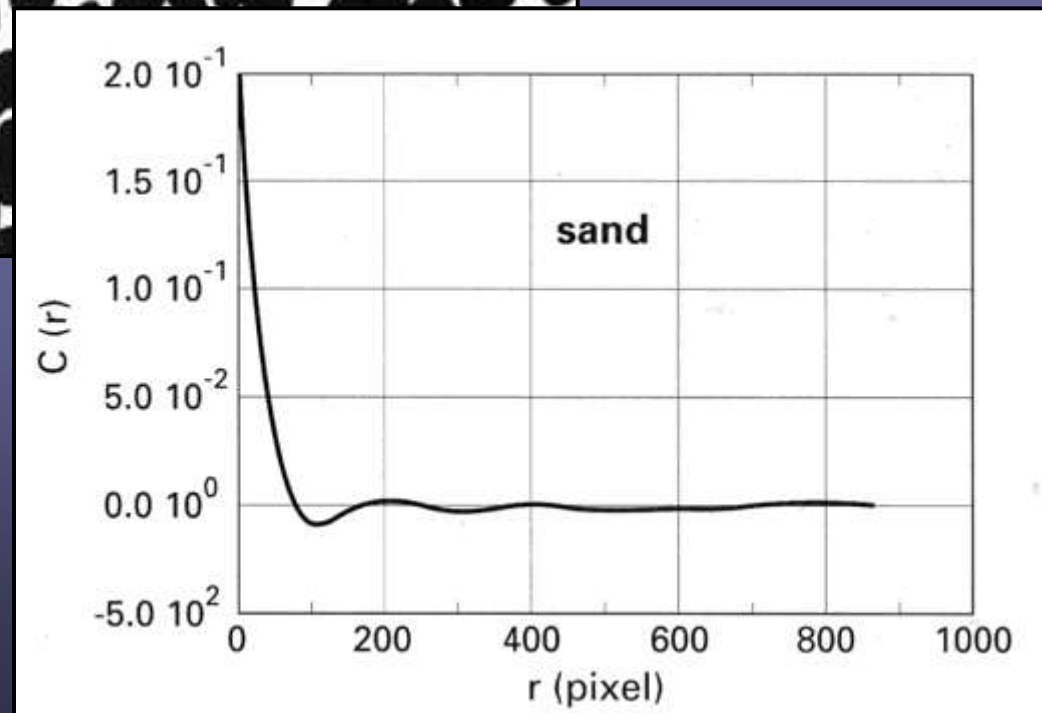
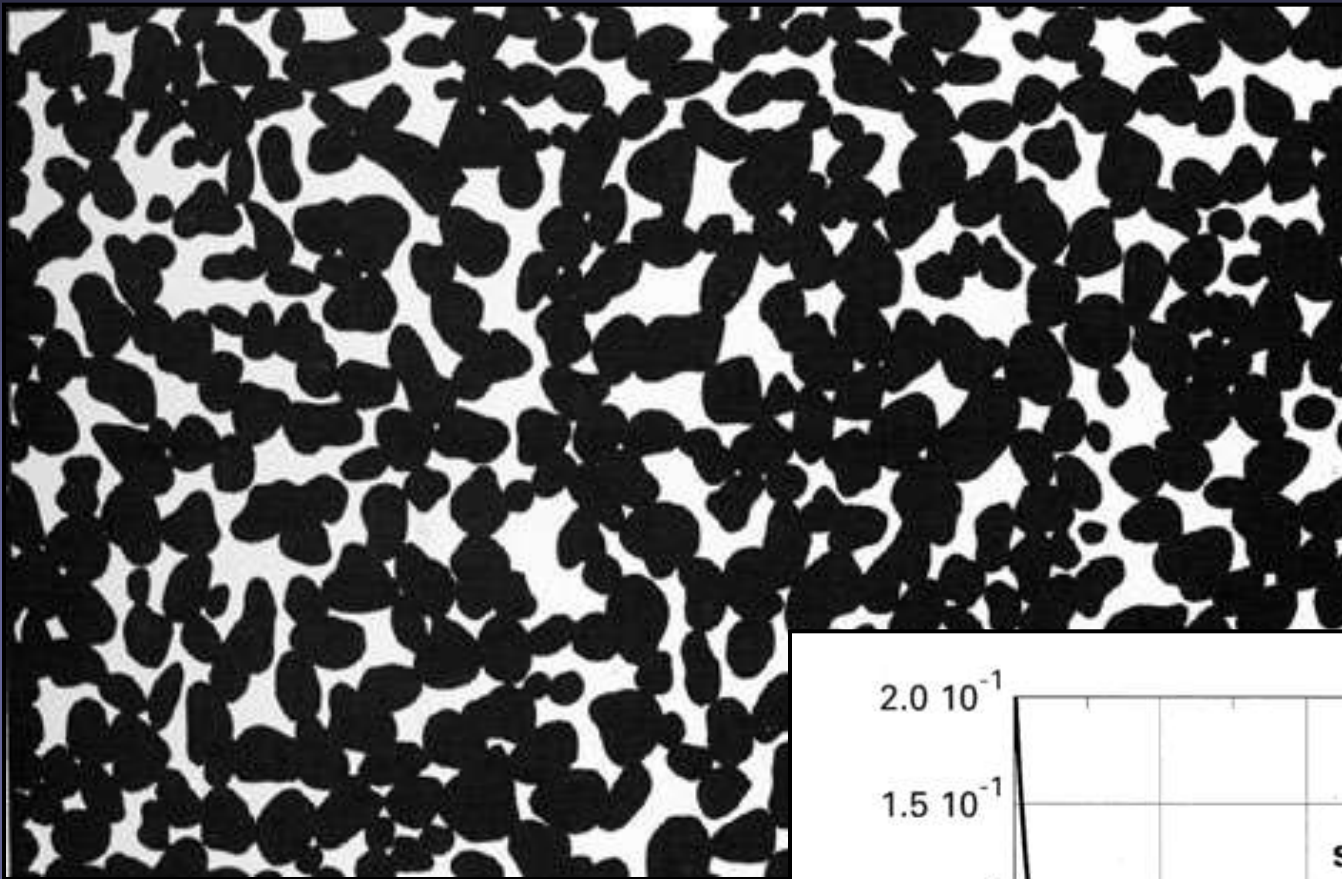


P. Levitz, D. Tchoubar



Bassin de Taoudeni



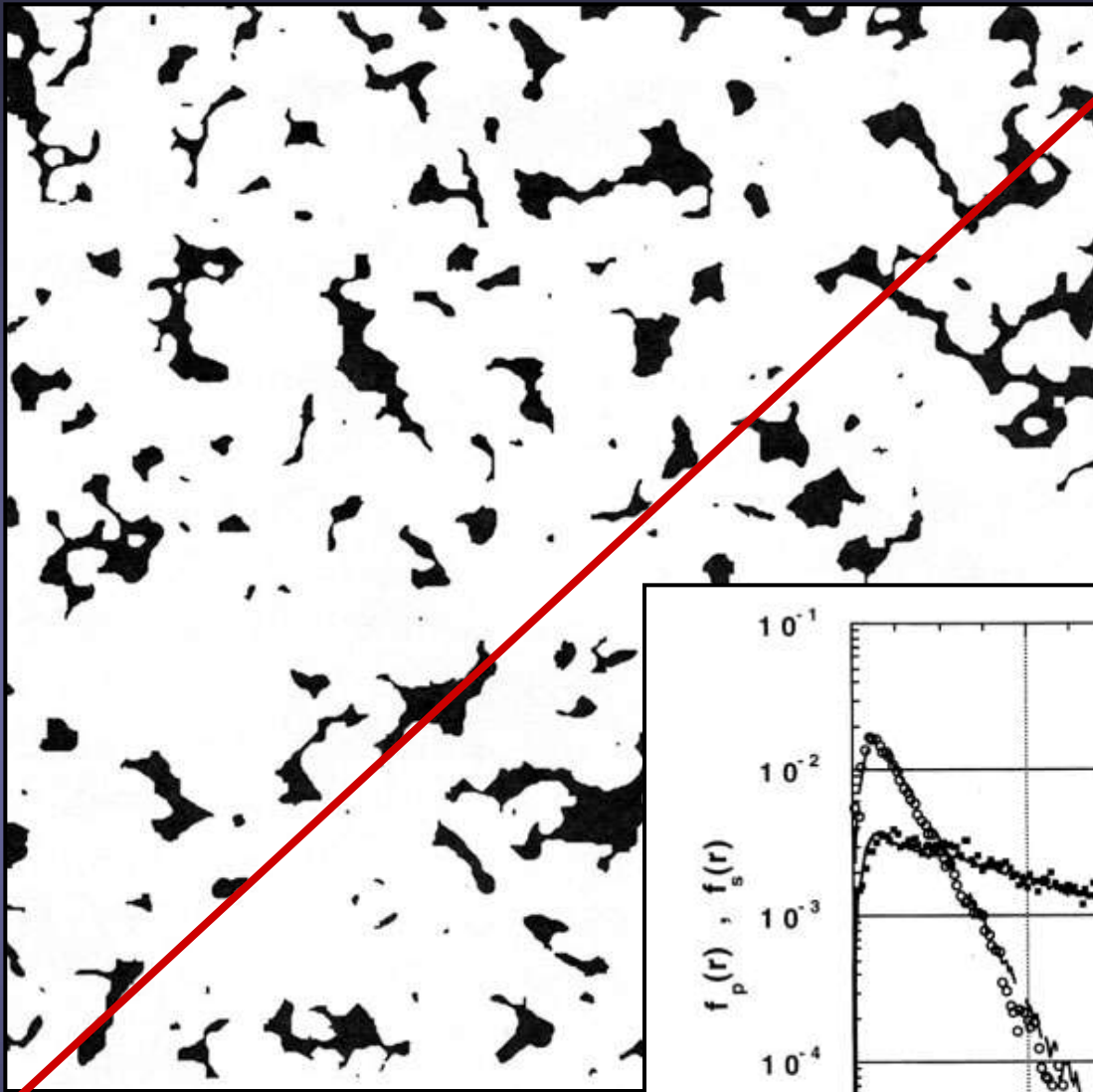


P. Levitz, HVD

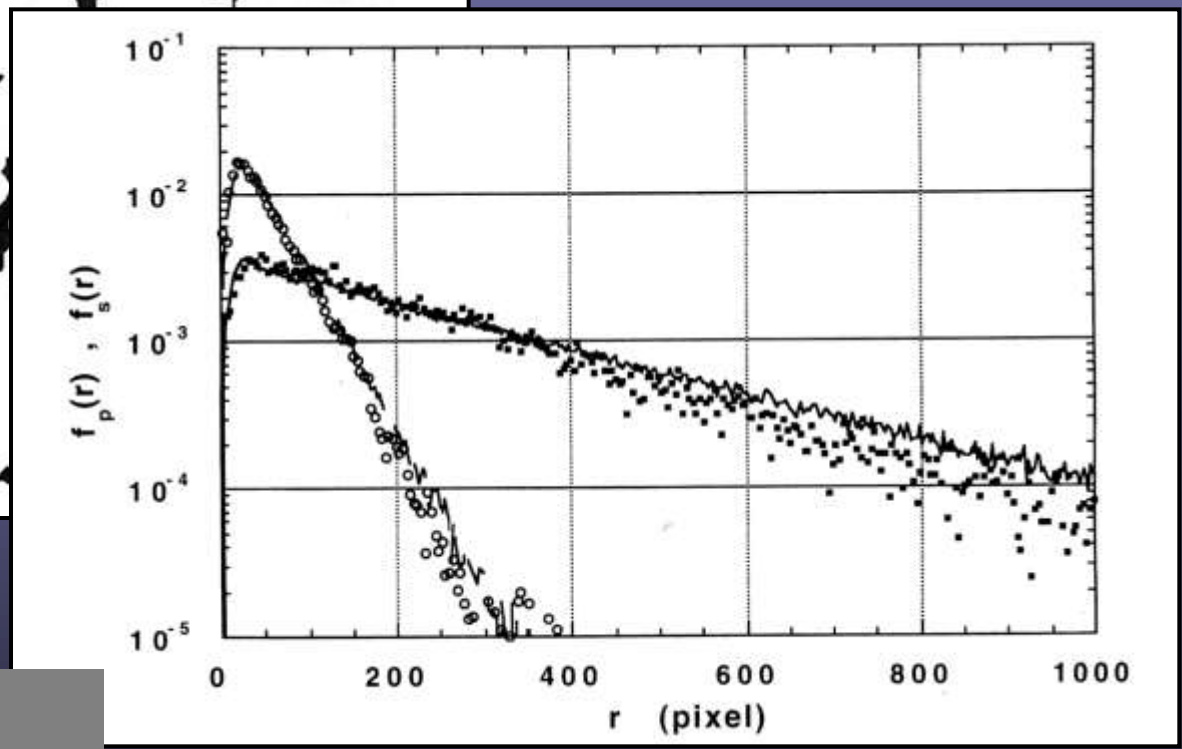


Calcaire à stromatolite, Adrar

10 Juin 2013, Inauguration MATeB L'espace Poreux un monde à part, H. Vandamme

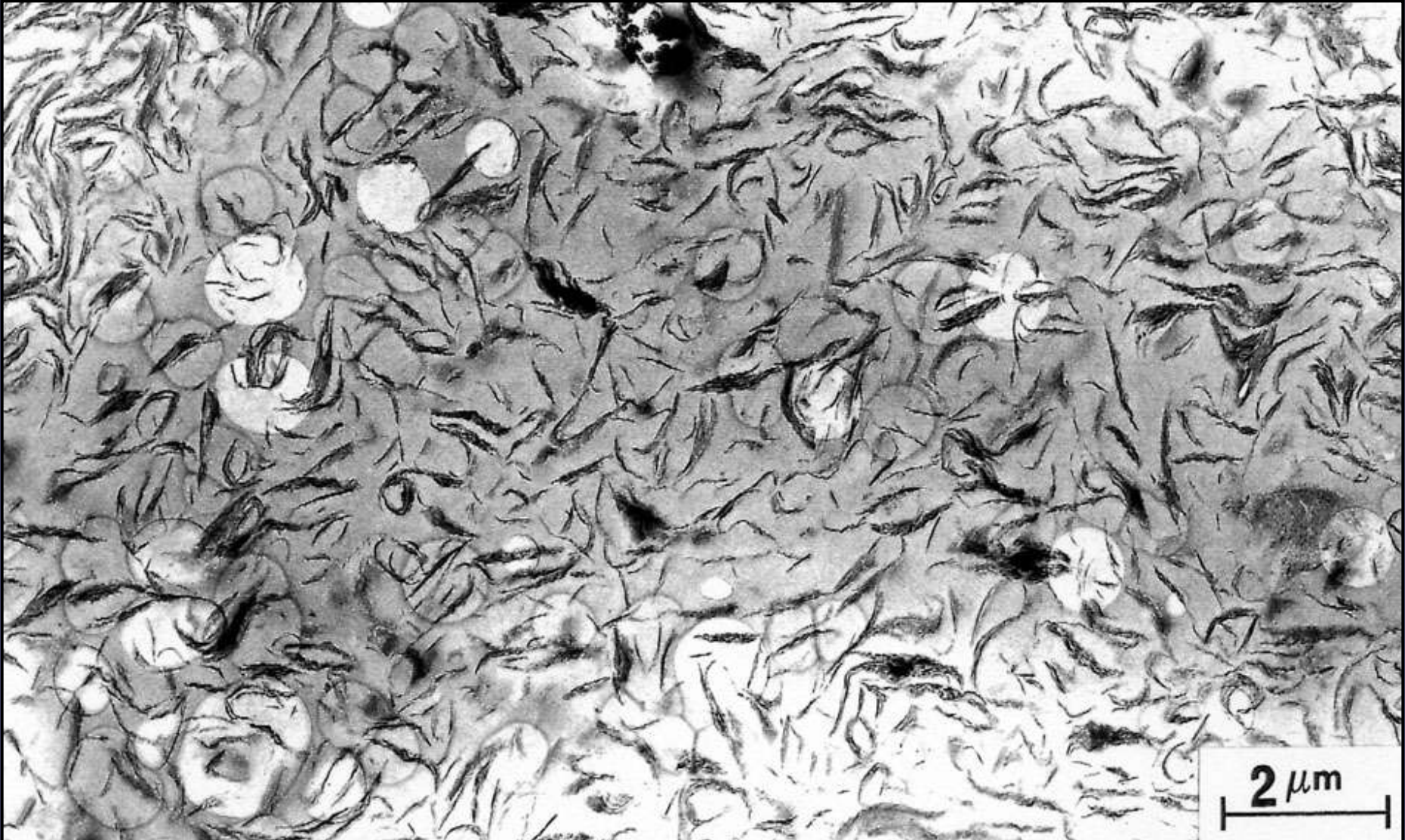


$$\frac{dN}{dr} = -kN$$



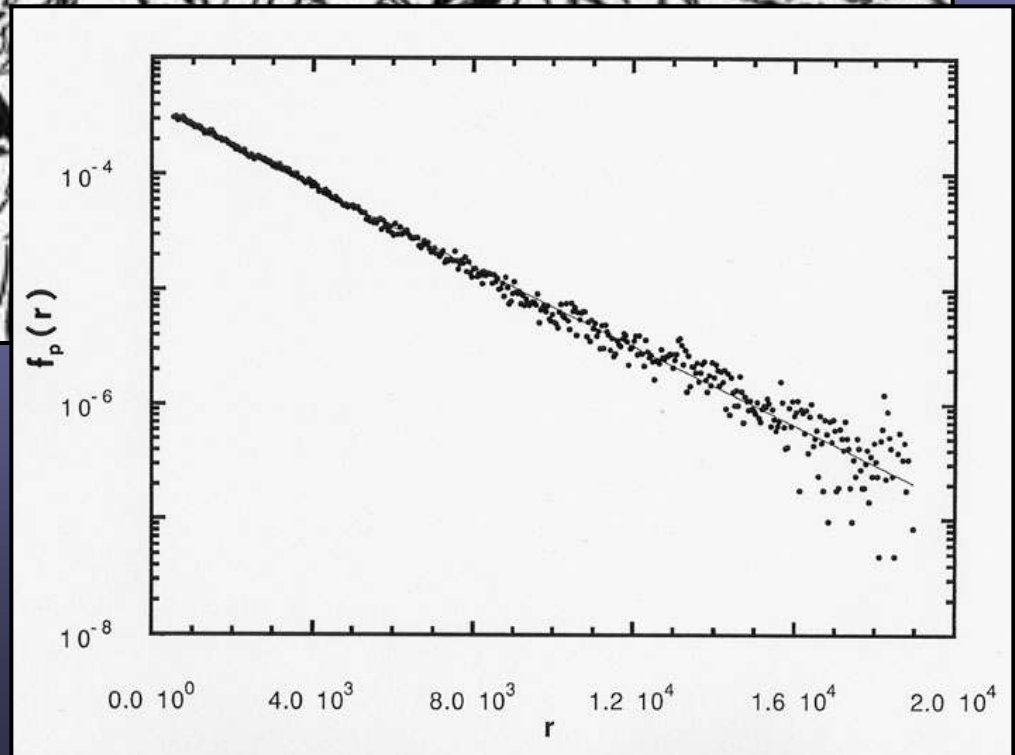
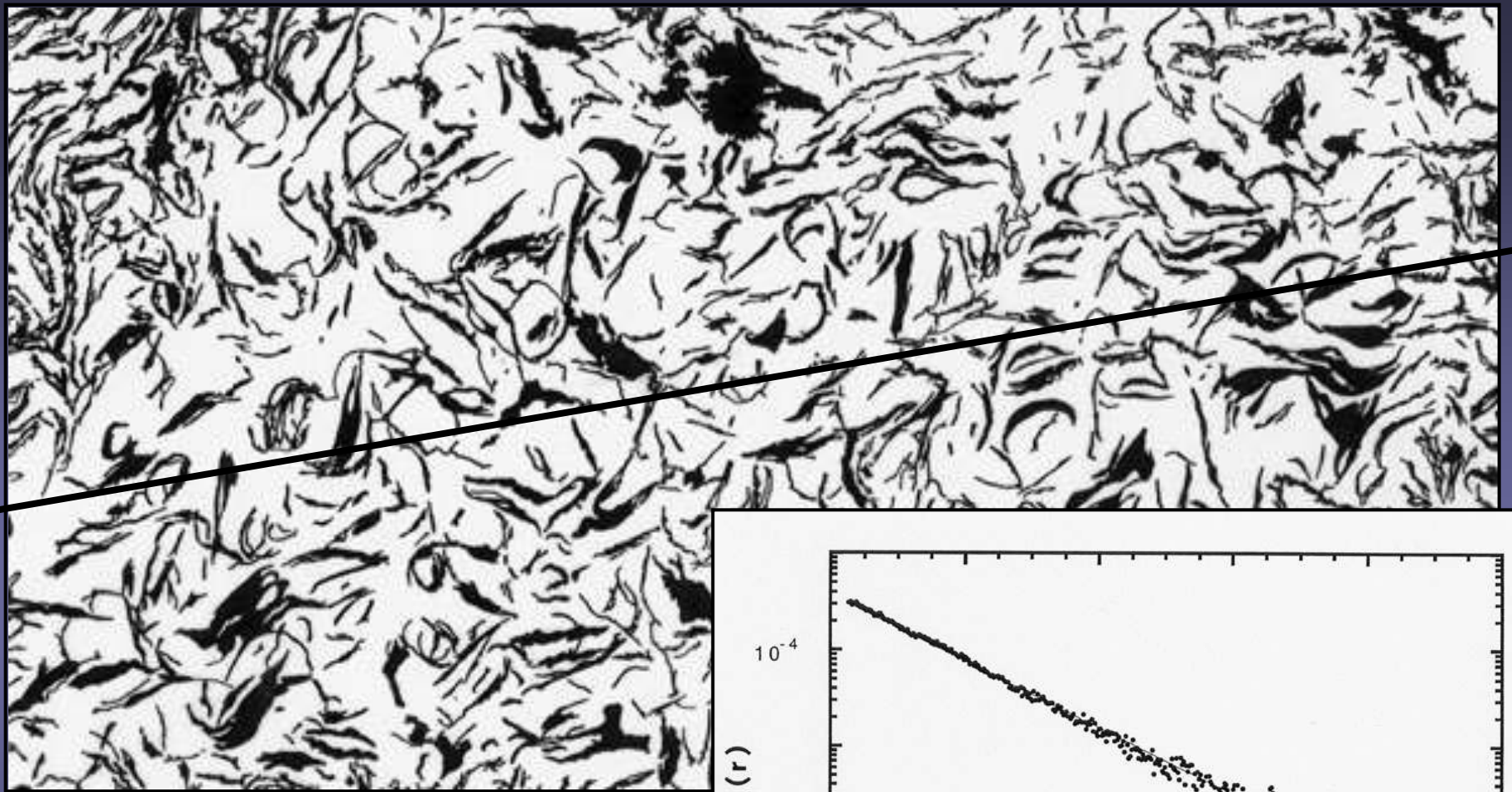
P. Levitz, D. Tchoubar

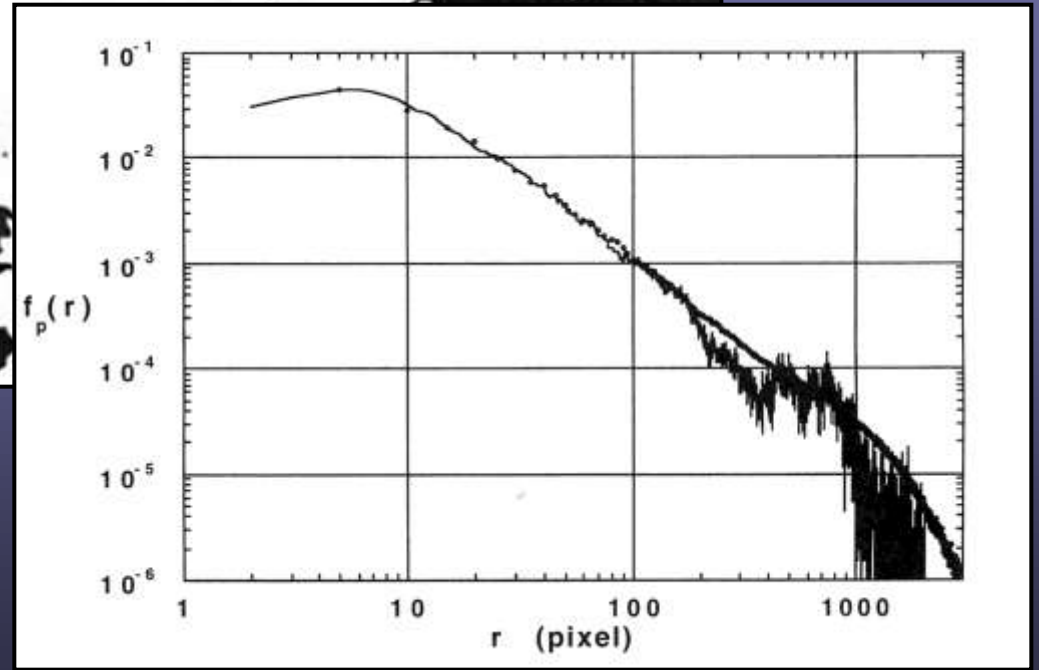
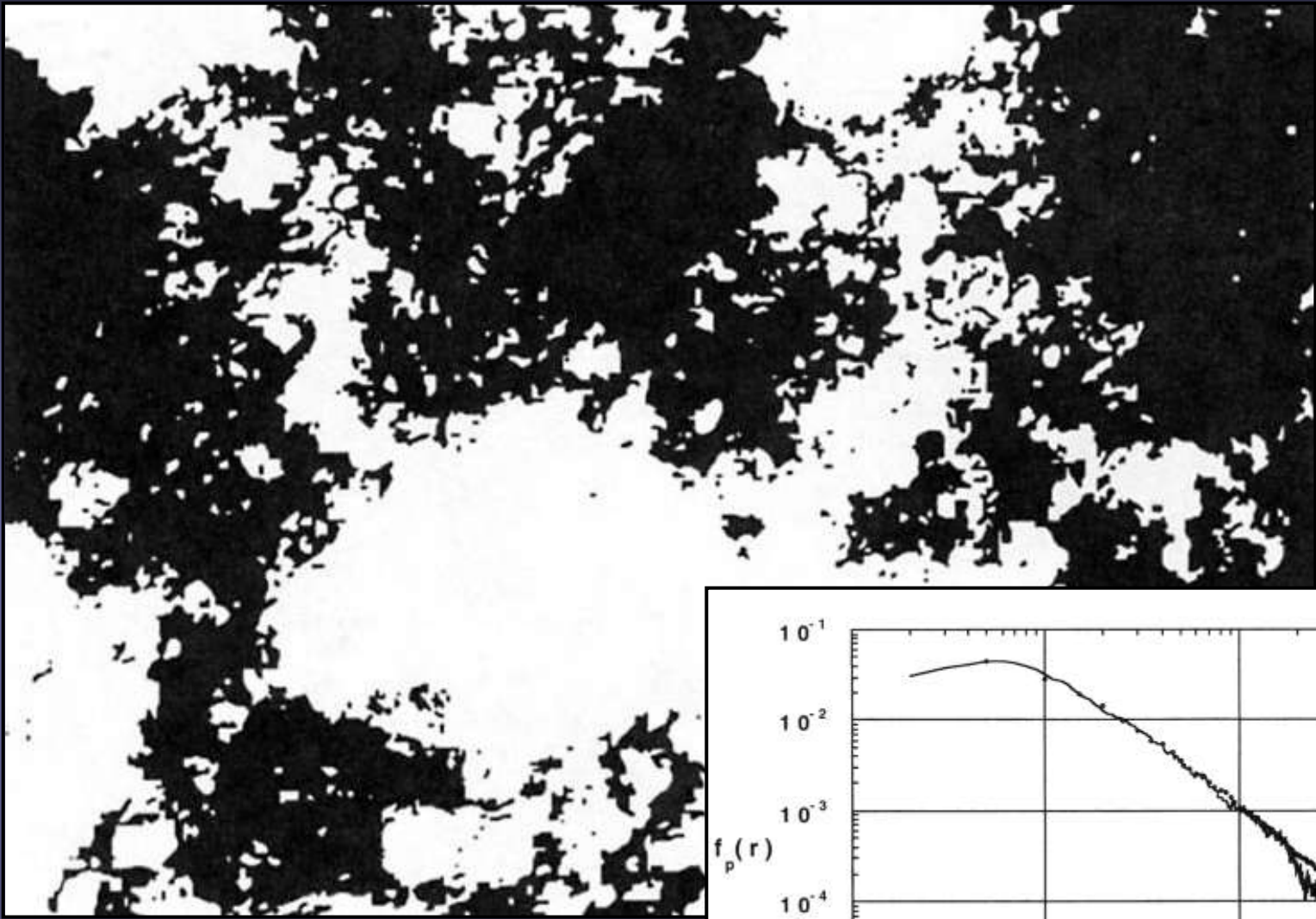




$pF = 2$ $P = 0.1 \text{ bar}$

H. Gaboriau, C. Clinard, C.H. Pons, F. Bergaya

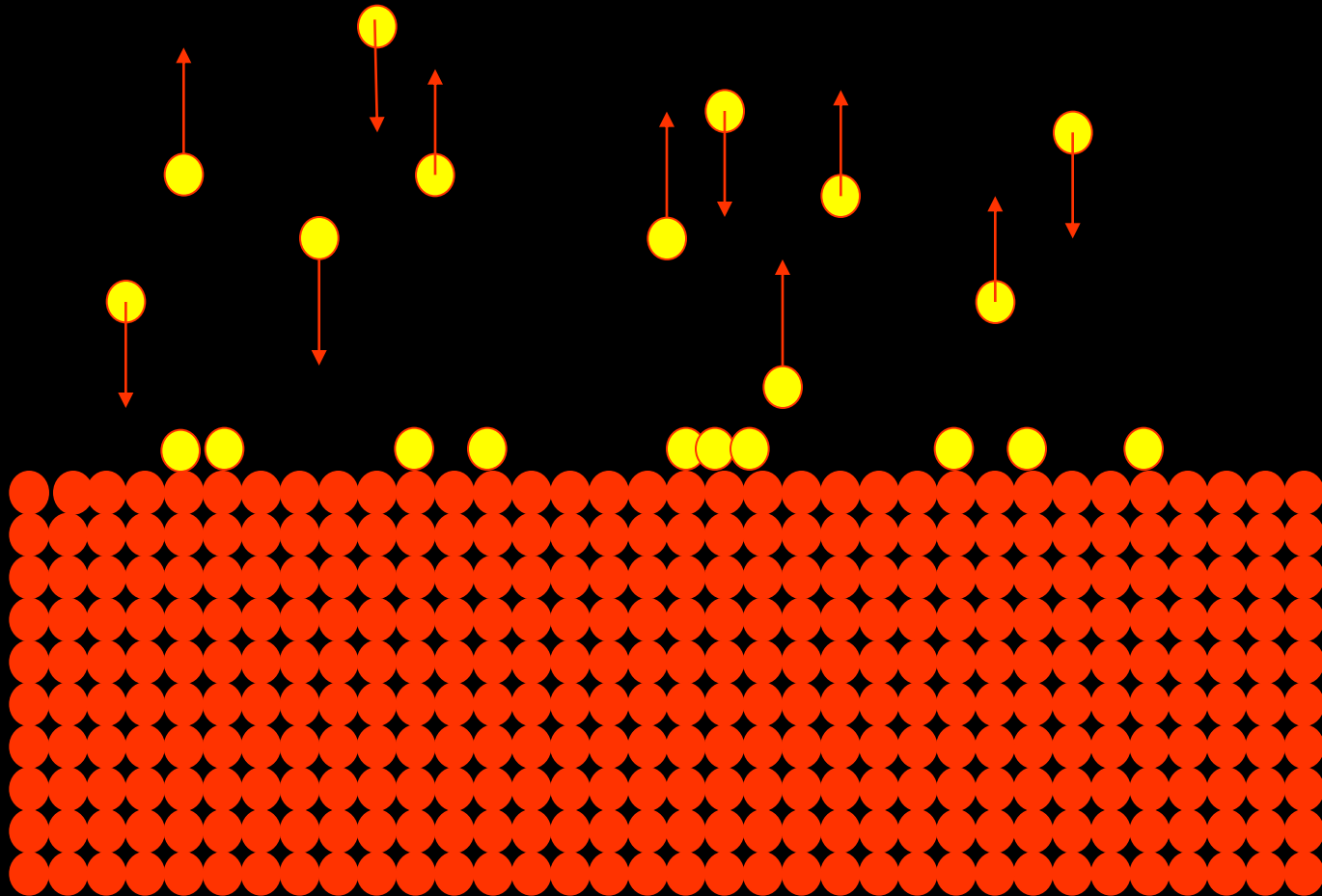




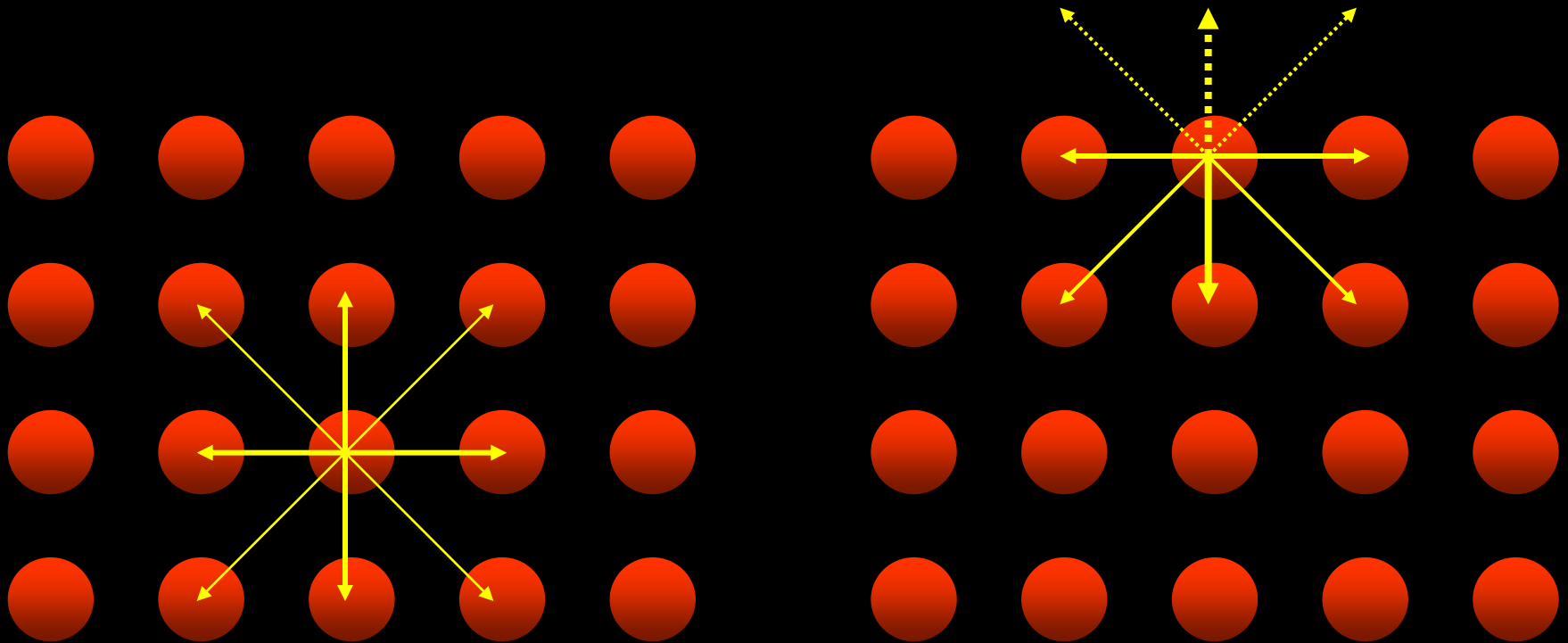
The background of the slide is a high-magnification scanning electron micrograph (SEM) of a porous material. The surface is highly textured, showing a complex network of interconnected fibers or plate-like structures that create a dense, porous network. The color palette is primarily dark blue and black, with bright white and light blue highlights that emphasize the intricate, three-dimensional structure of the material. A semi-transparent rectangular box is overlaid in the upper-middle section of the image, containing the title text.

Une paroi adsorbante

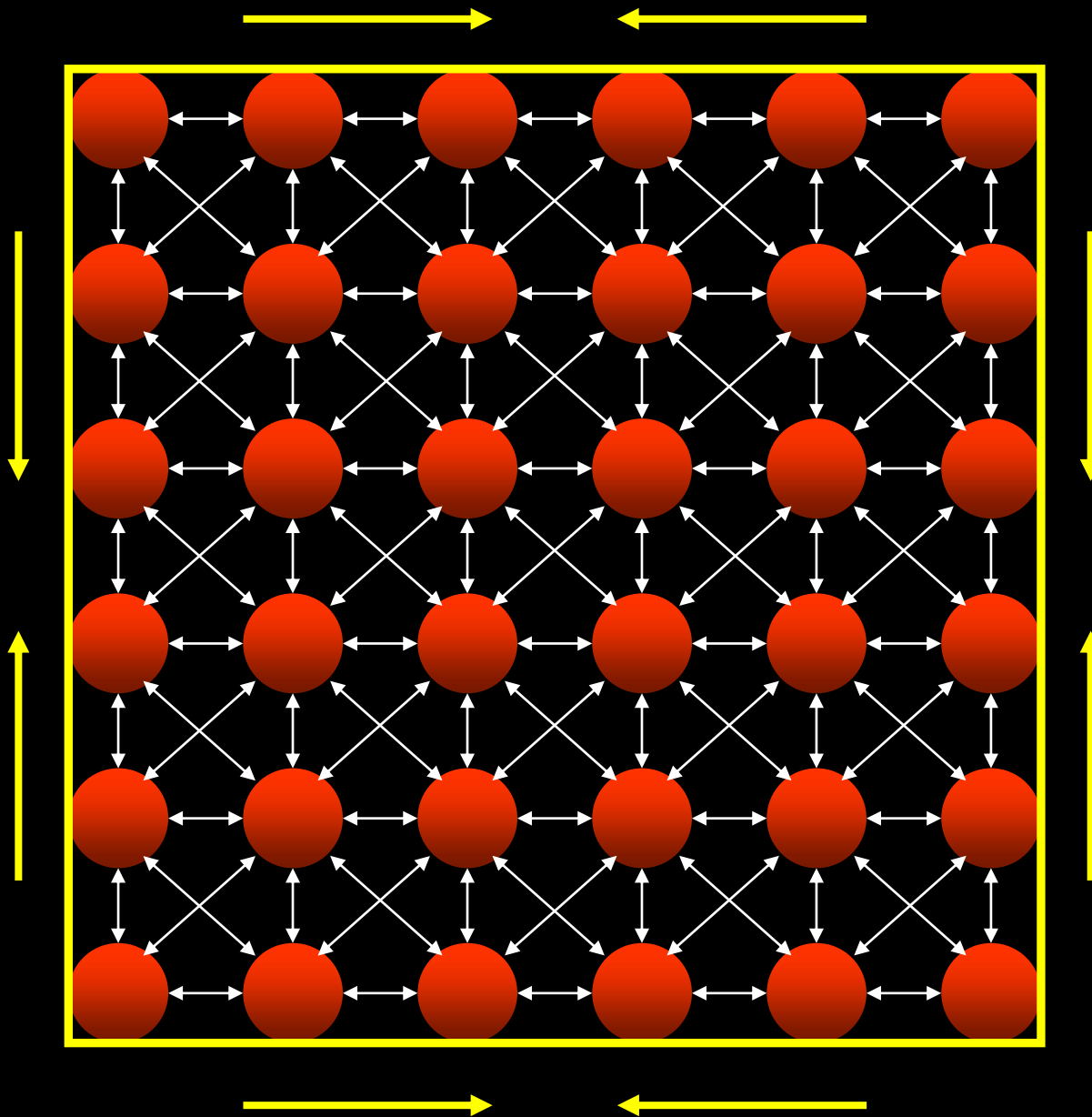




Il manque des liaisons aux atomes de surface



De plus, ils ne sont pas soumis à un champ de forces symétrique, comme leurs homologues du volume



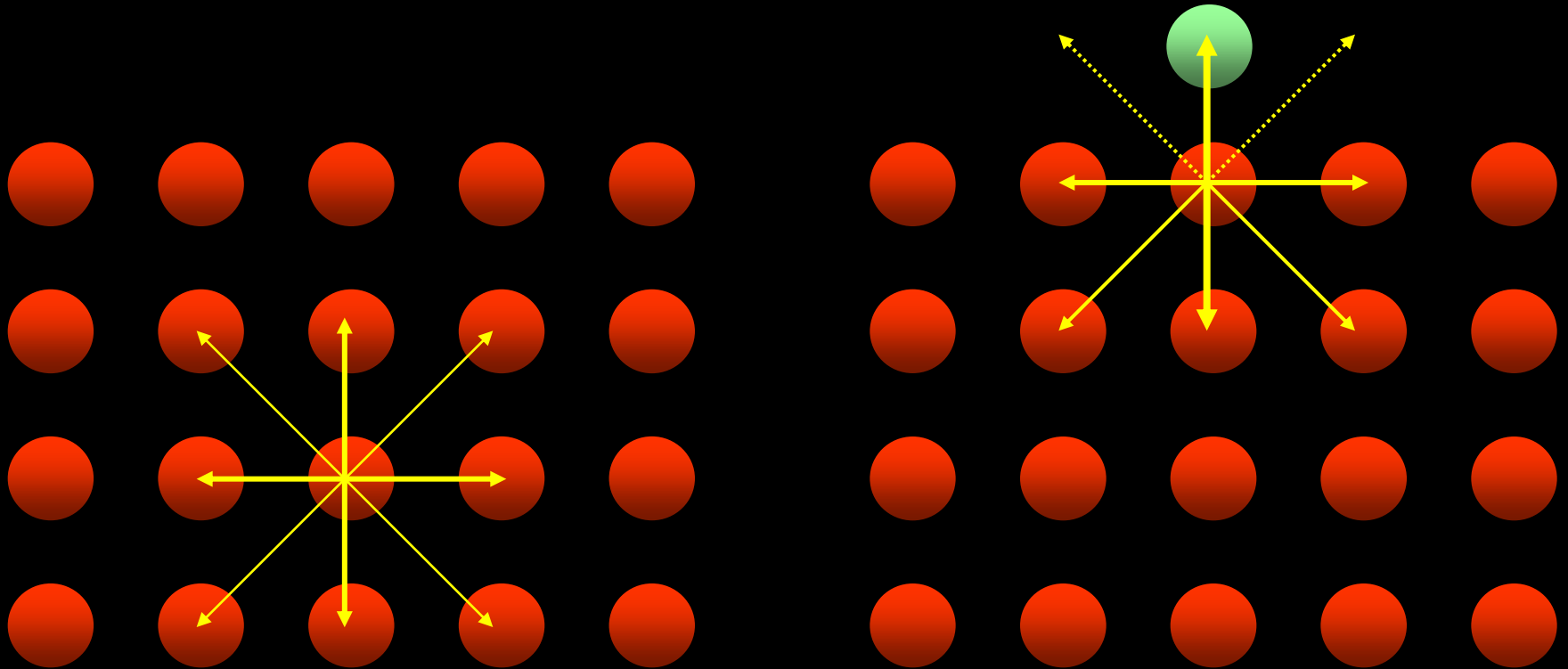
Tout se passe comme si un élastique entourait le solide...

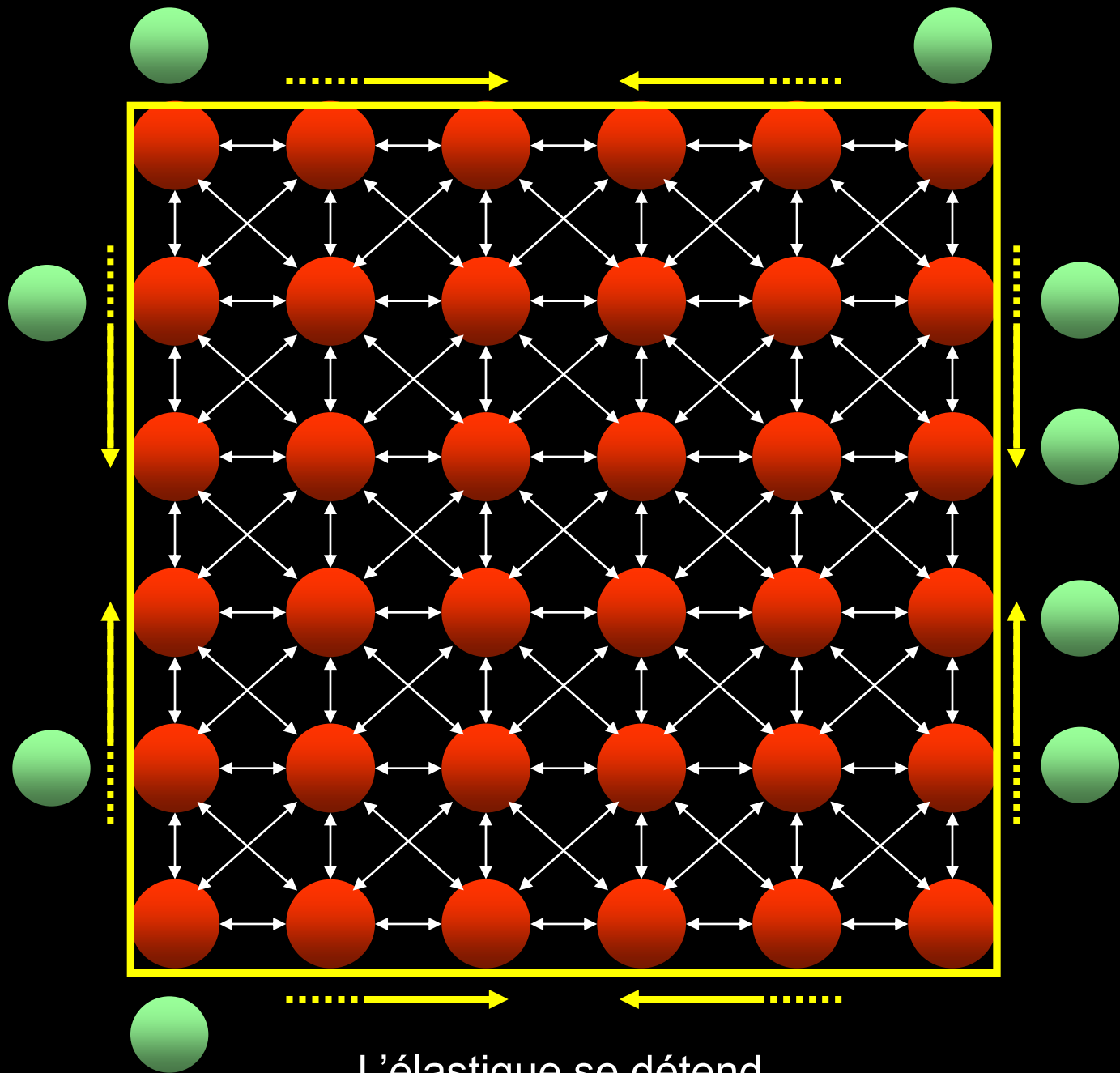
Irving – Kirkwood (1950)

Irving, J. H. ; Kirkwood, J. G.; J. Chem. Phys. 1950, 18, 817–829

$$\gamma_{IK} = \frac{1}{2} \int_0^{L_z} (P_N(z) - P_T(z)) dz$$

Que fait l'adsorption ? Elle en remet une couche !



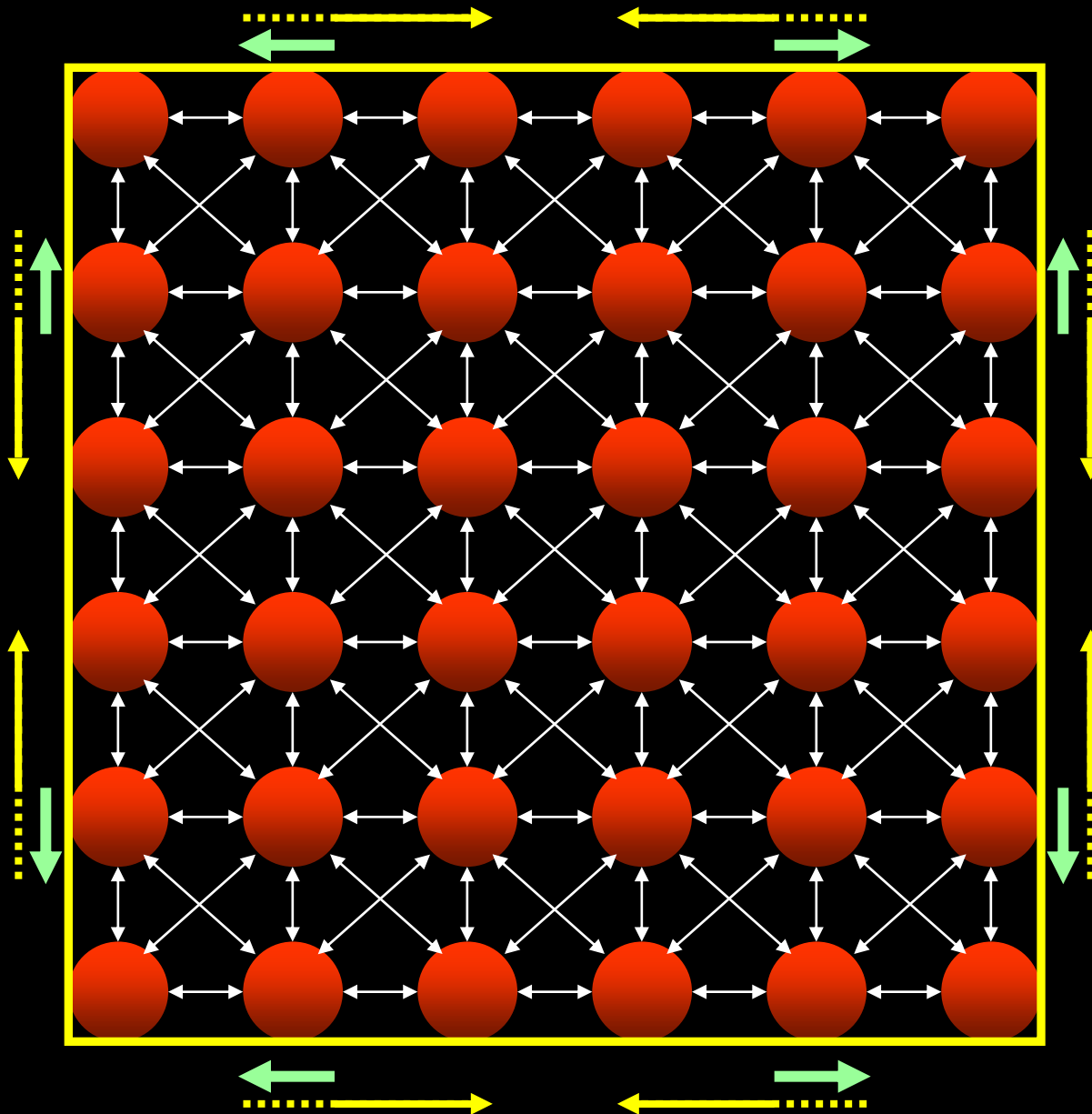


L'élastique se détend...
(l'énergie et la tension interfaciales diminuent)

$$d\gamma_{SV} = -\frac{n_s}{A} RTd \ln a$$

Gibbs a montré que la densité surfacique de molécules adsorbées est directement reliée à la baisse d'énergie interfaciale qu'elles produisent.

(ou, inversement, que la diminution d'énergie interfaciale est proportionnelle à la quantité adsorbée)



Tout se passe comme si une force d'étalement venait contrecarrer la tendance du solide (ou du liquide) à se recroqueviller sur lui-même

On appelle pression d'étalement (ou pression bidimensionnelle) cette force (par unité de longueur) qui représente la différence entre la tension superficielle dans le vide et la tension interfaciale.

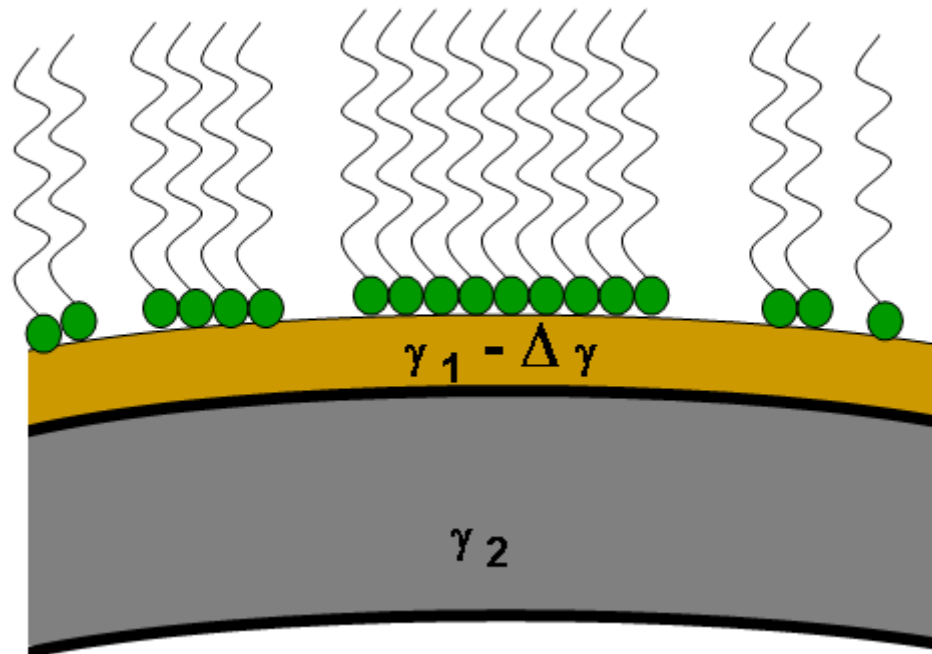
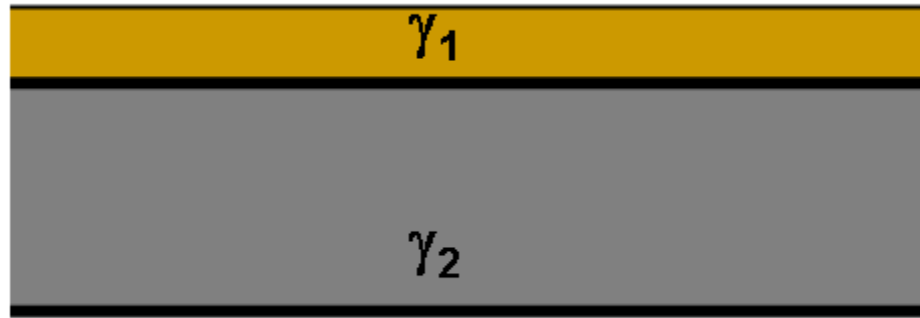
$$\pi = \gamma_S - \gamma_{SV}$$

$$\pi = RT \int_0^P \Gamma_S d \ln P$$

$$\Gamma_S = \frac{N_S}{A}$$

D.H. Bangham, Trans. Faraday Soc., **33**, 803 (1937)

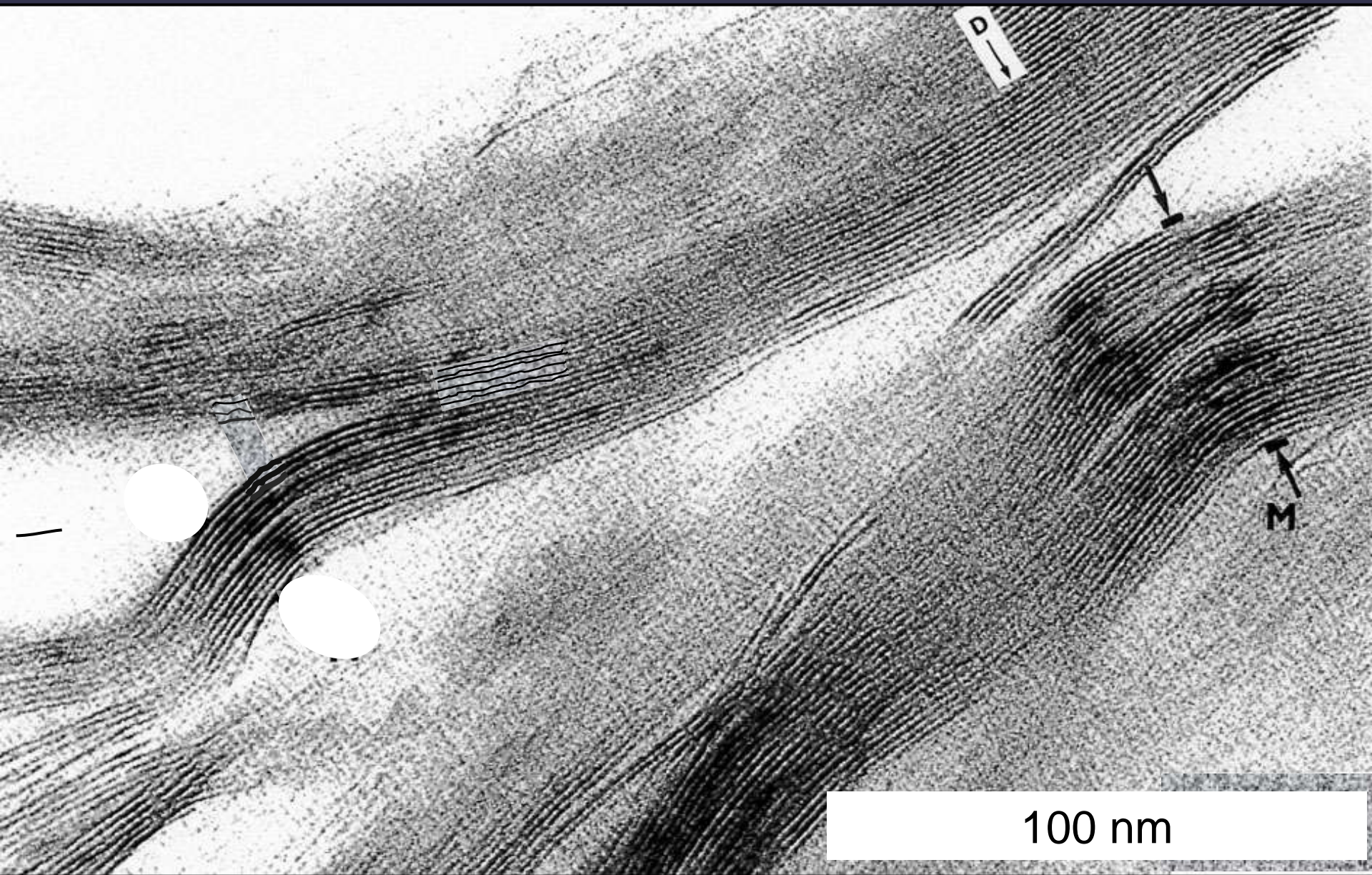
On peut facilement mesurer ses effets !

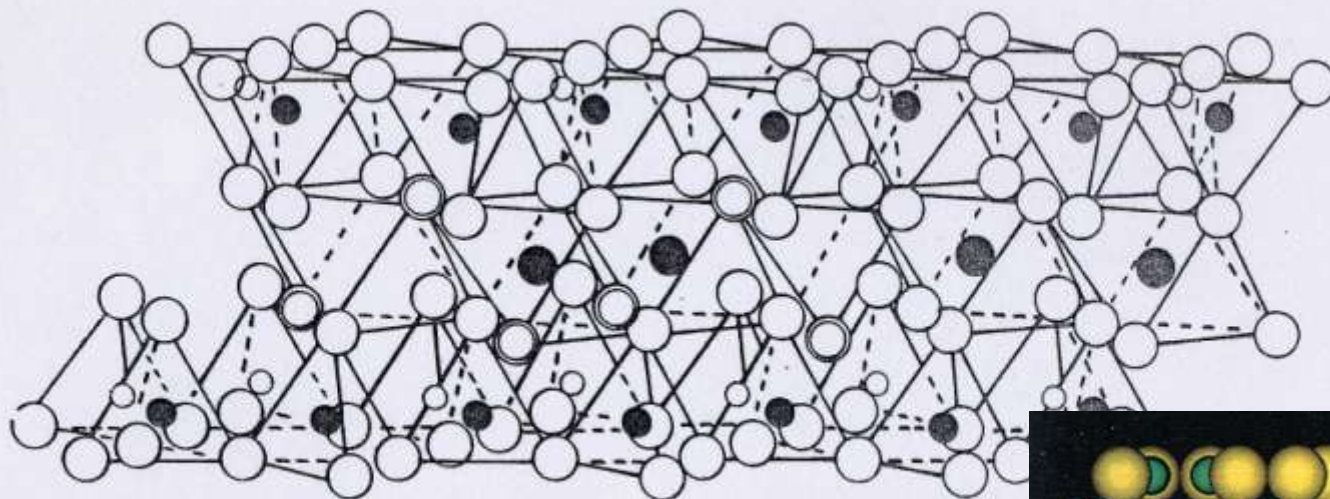




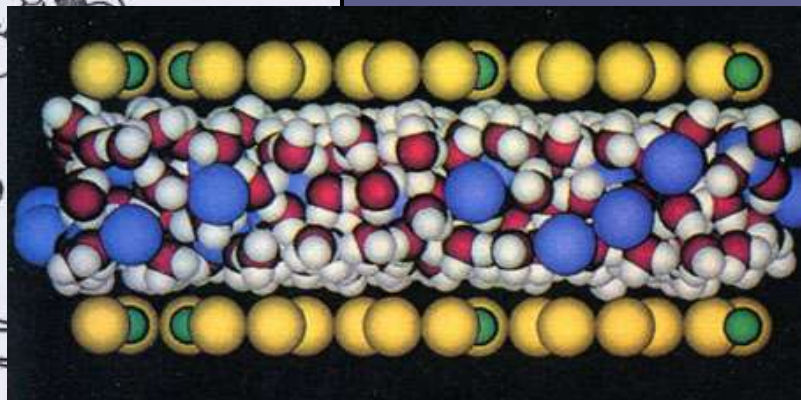
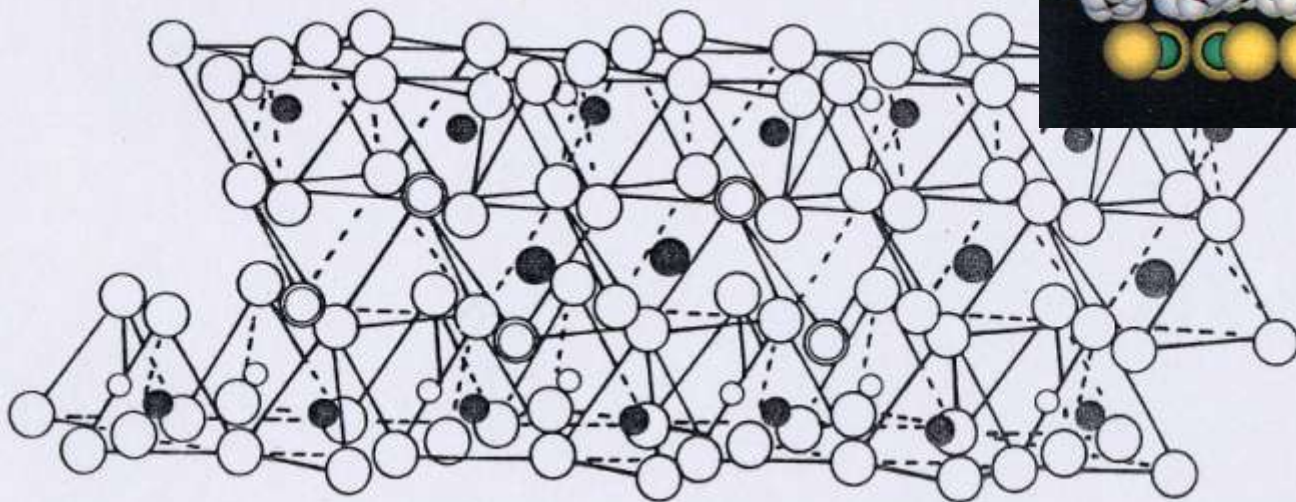
L'adsorption conduit au « gonflement »
ou « dégonflement » des milieux poreux





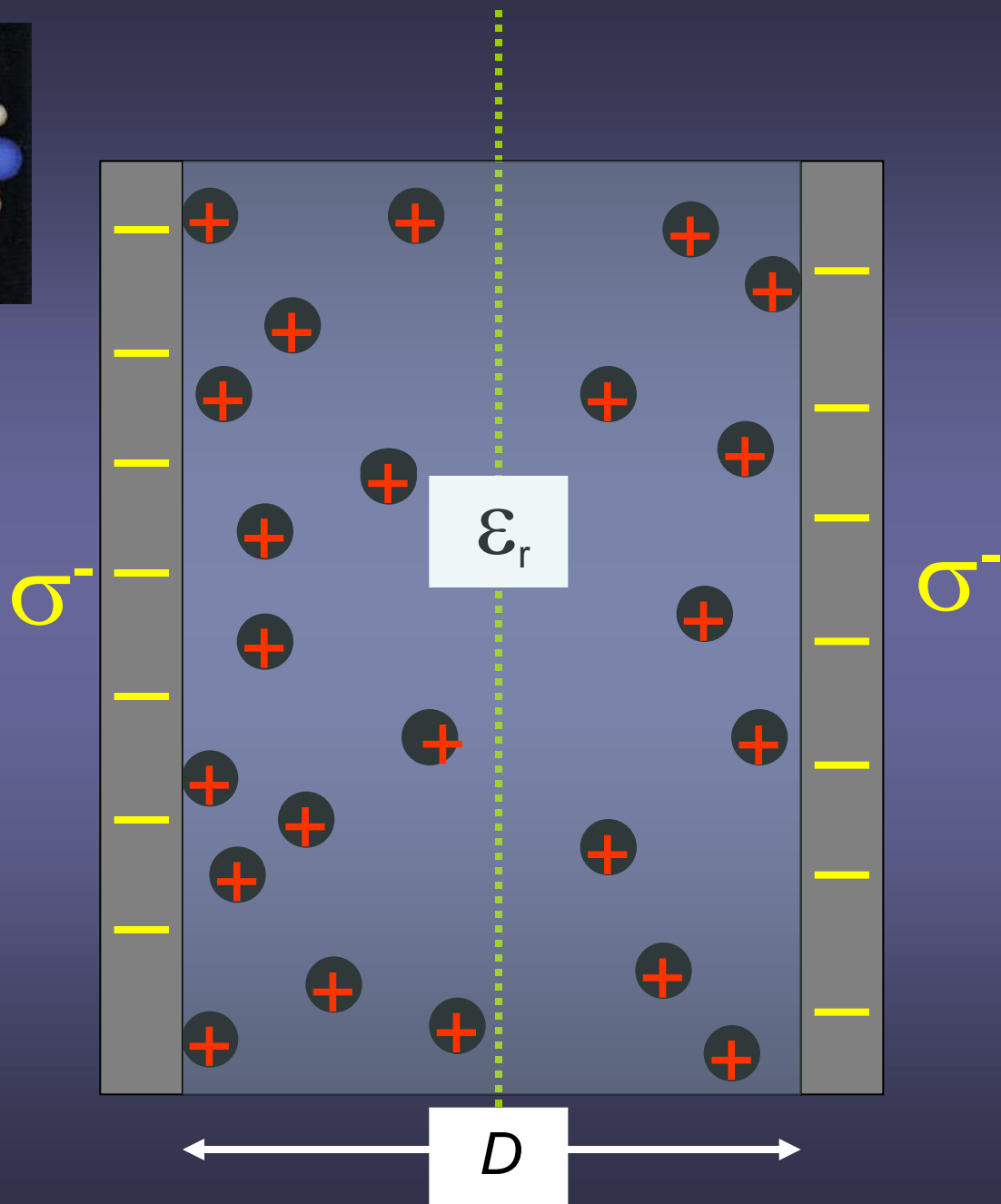
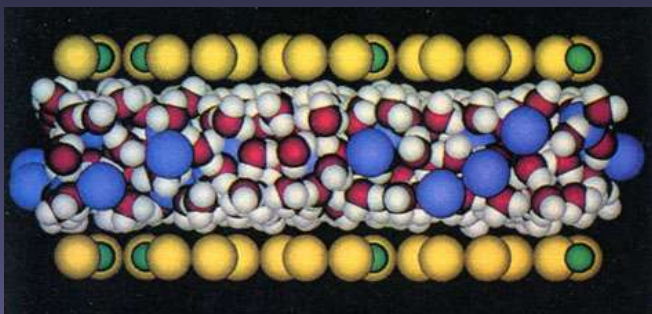


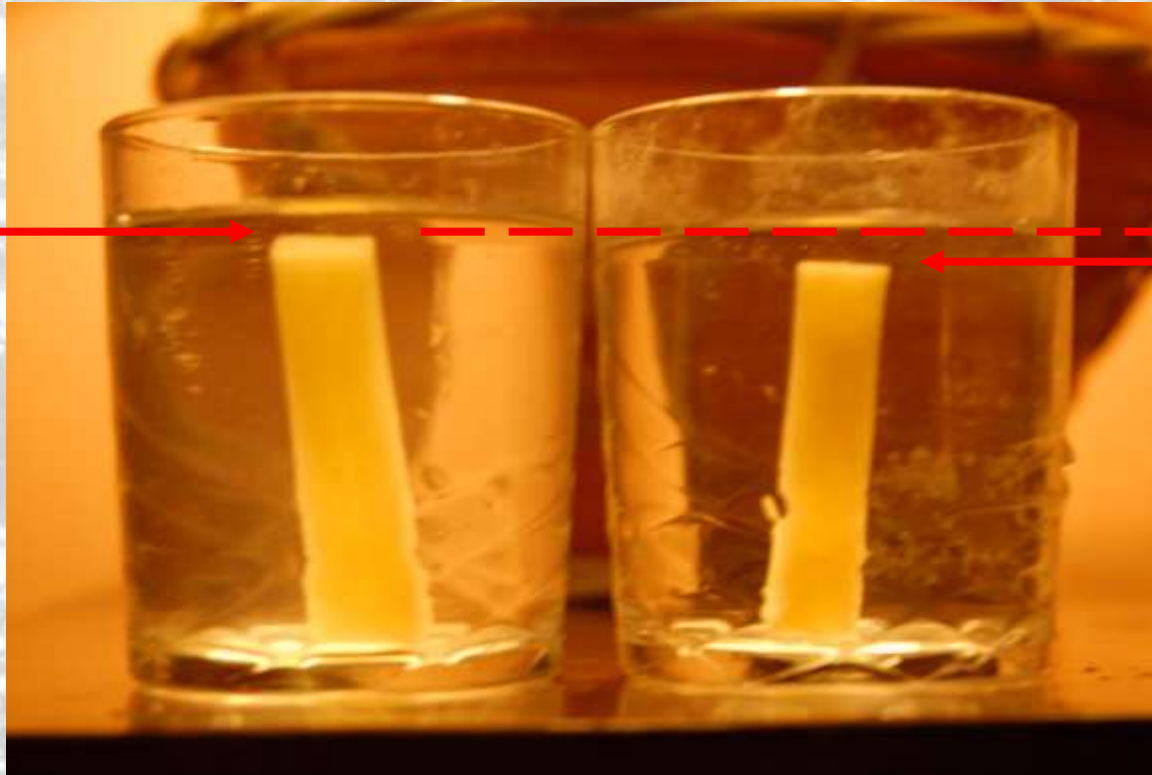
EXCHANGEABLE CATIONS , $n \text{ H}_2\text{O}$









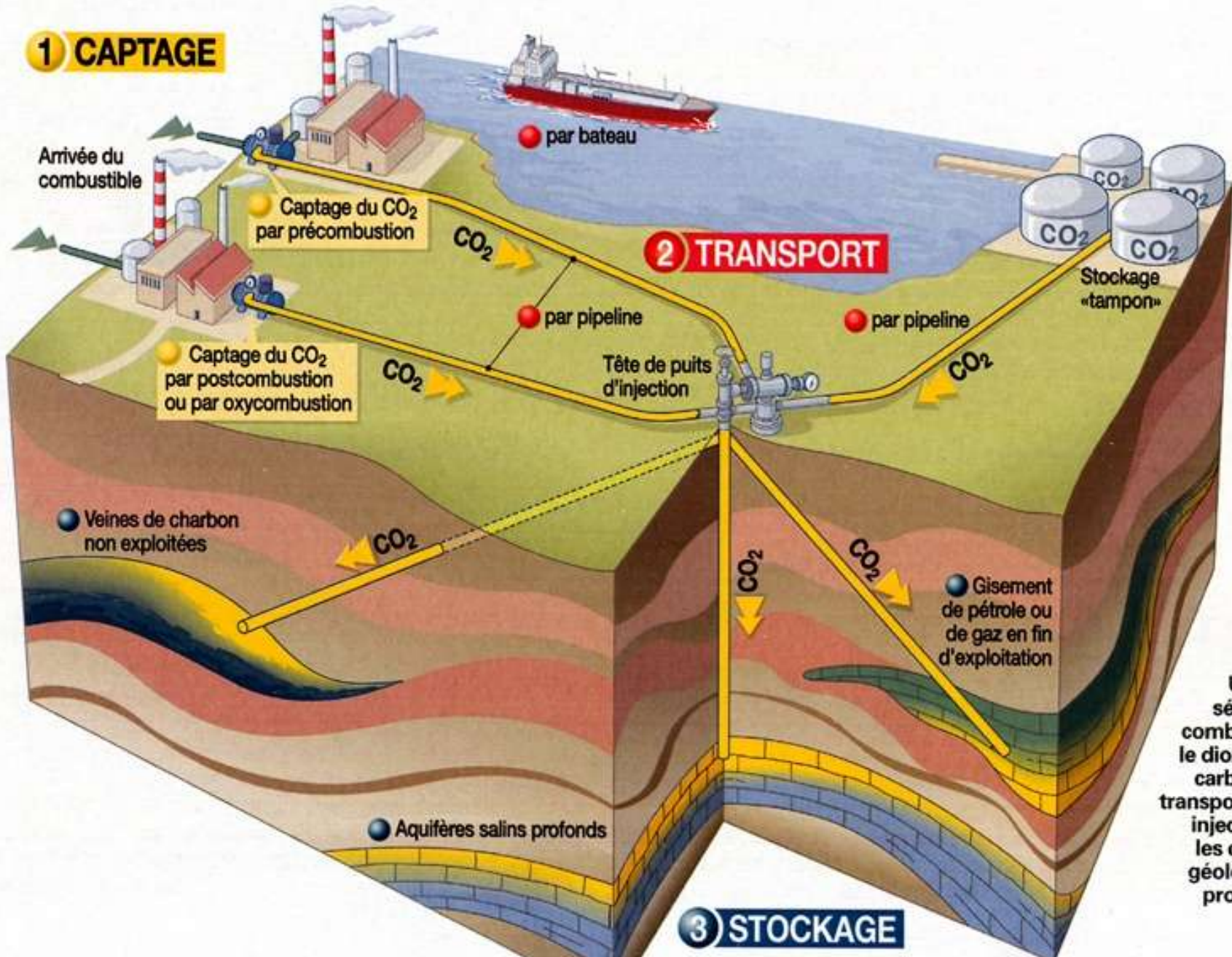


Eau pure

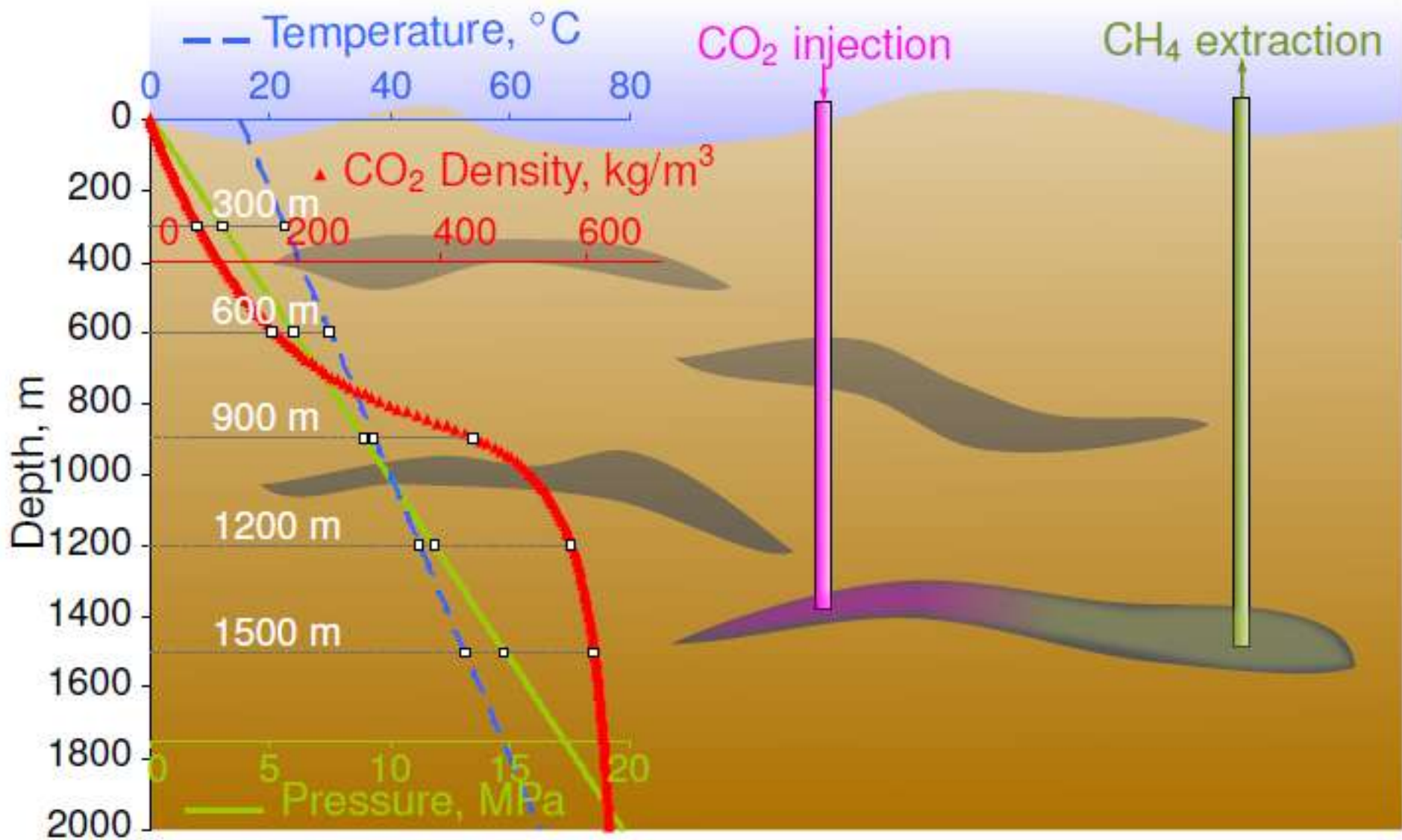
1 N NaCl

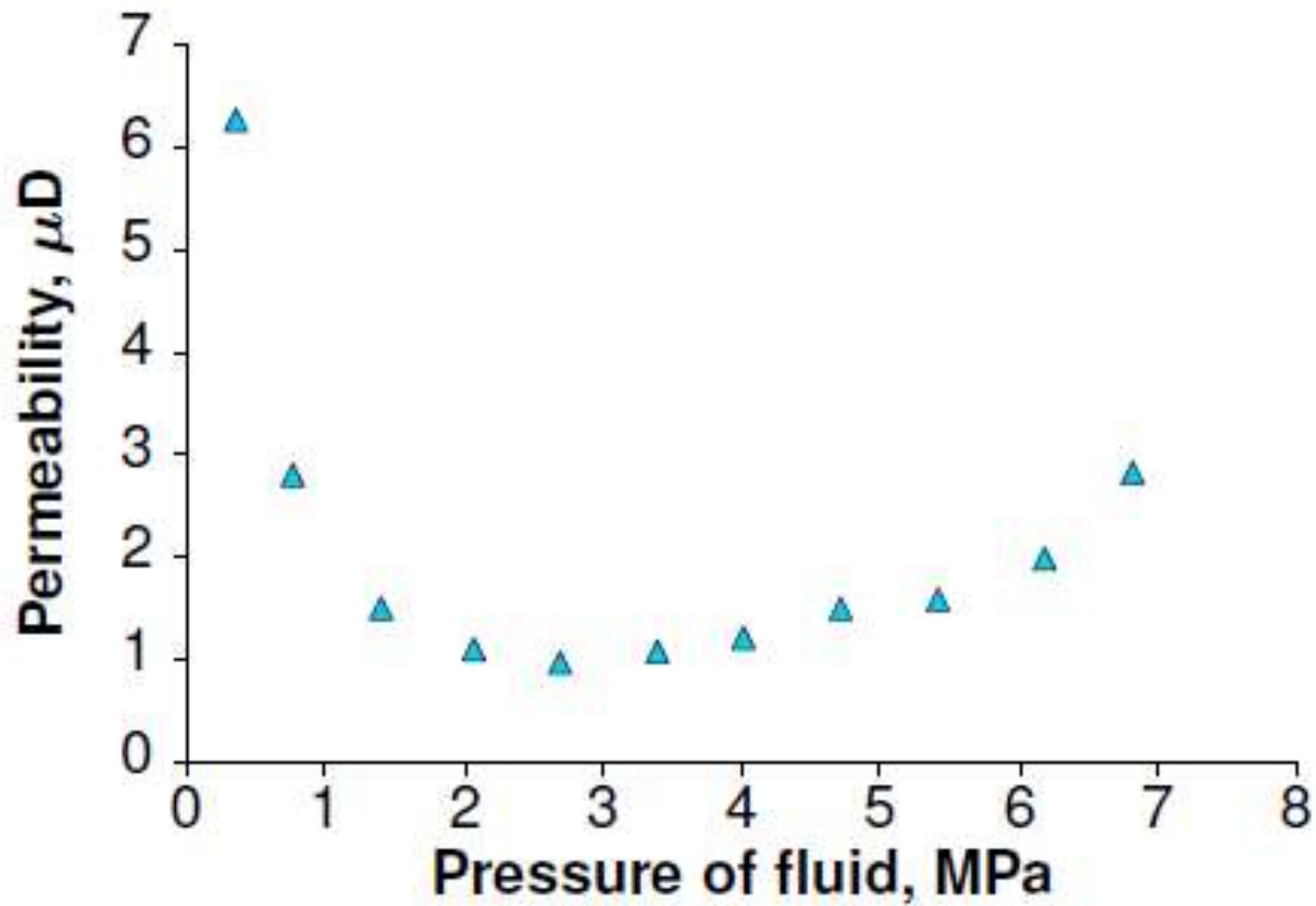
COMMENT ON PIÈGE LE CO₂

1 CAPTAGE

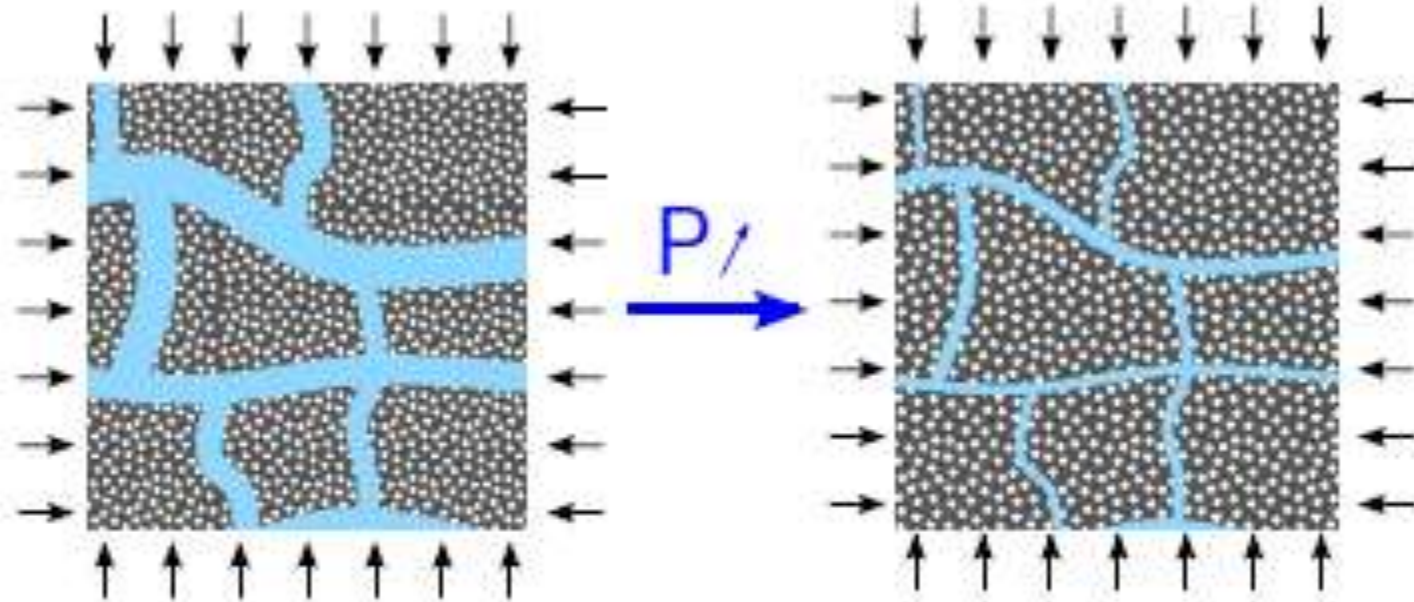


Une fois séparé du combustible, le dioxyde de carbone est transporté puis injecté dans les couches géologiques profondes.

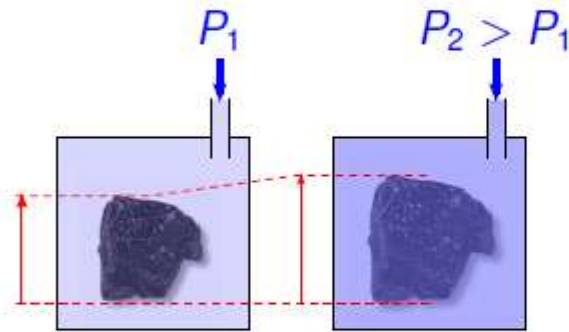




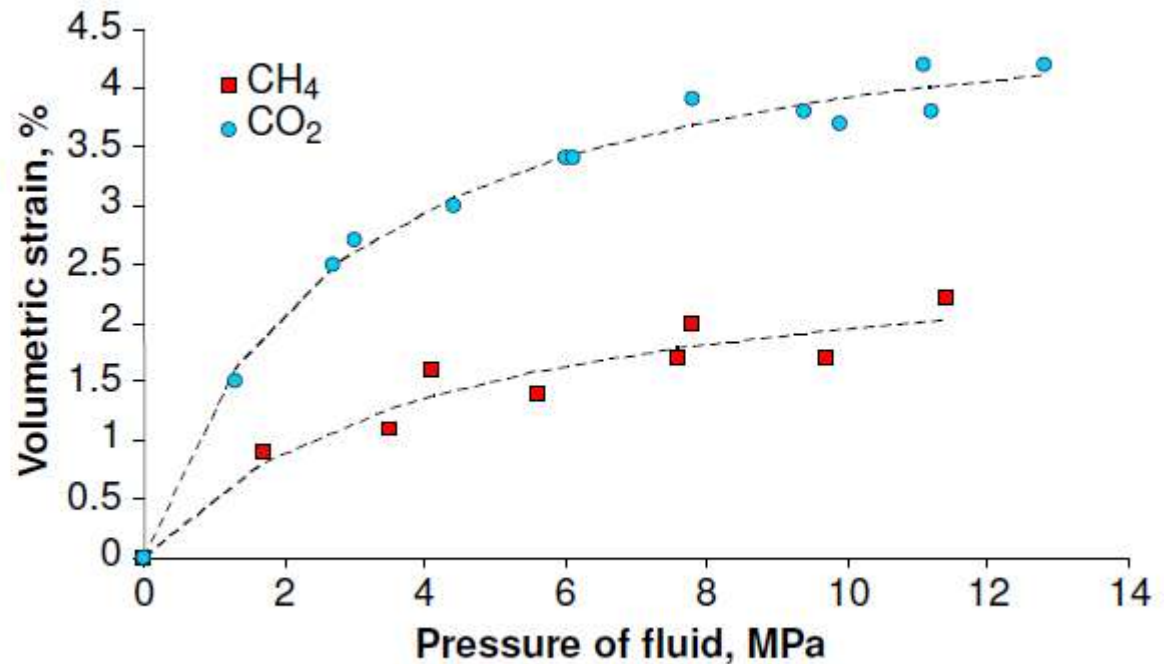
Les fissures se ferment



Le charbon gonfle !

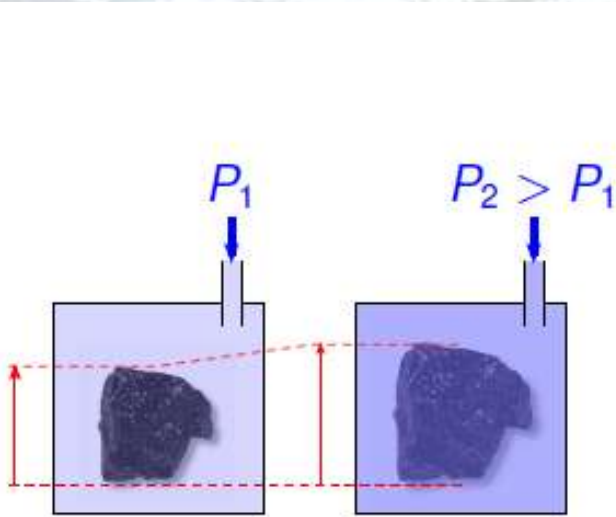


Adapted from Ottiger et al. (2008)

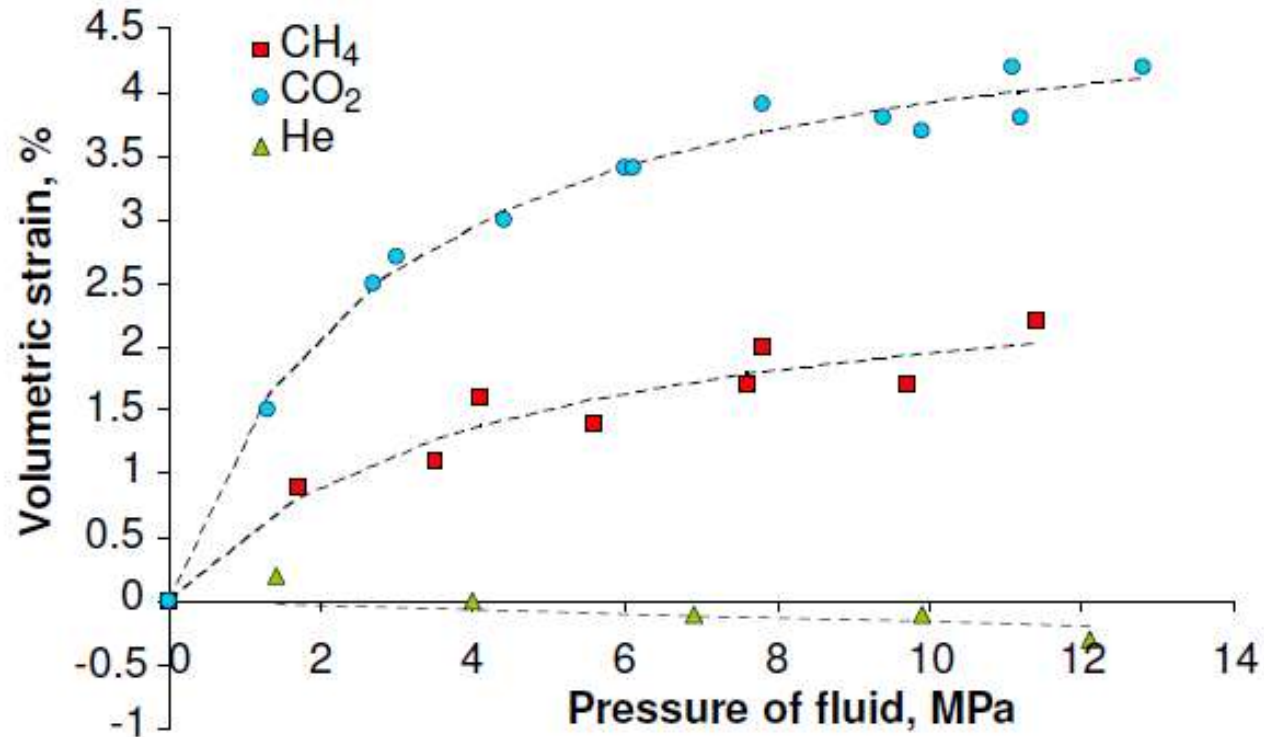


et il gonfle plus dans le CO_2 que dans le CH_4 !

Et dans l'hélium, il ne gonfle pas du tout !



Adapted from [Ottiger et al. \(2008\)](#)



Extended state equations

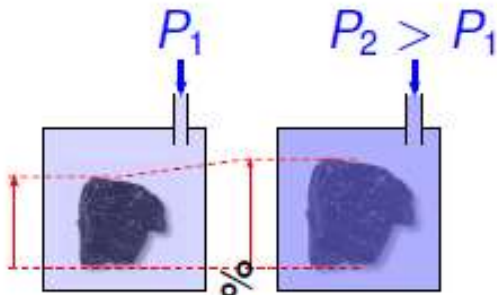
$$\sigma = K\epsilon - \frac{\partial}{\partial \epsilon} \left[\int_0^P \tilde{n} \bar{V}_{bulk} dP \right]_{e_{ab}, T, P}$$

$$\tilde{n} = \tilde{n}(\epsilon, P)$$

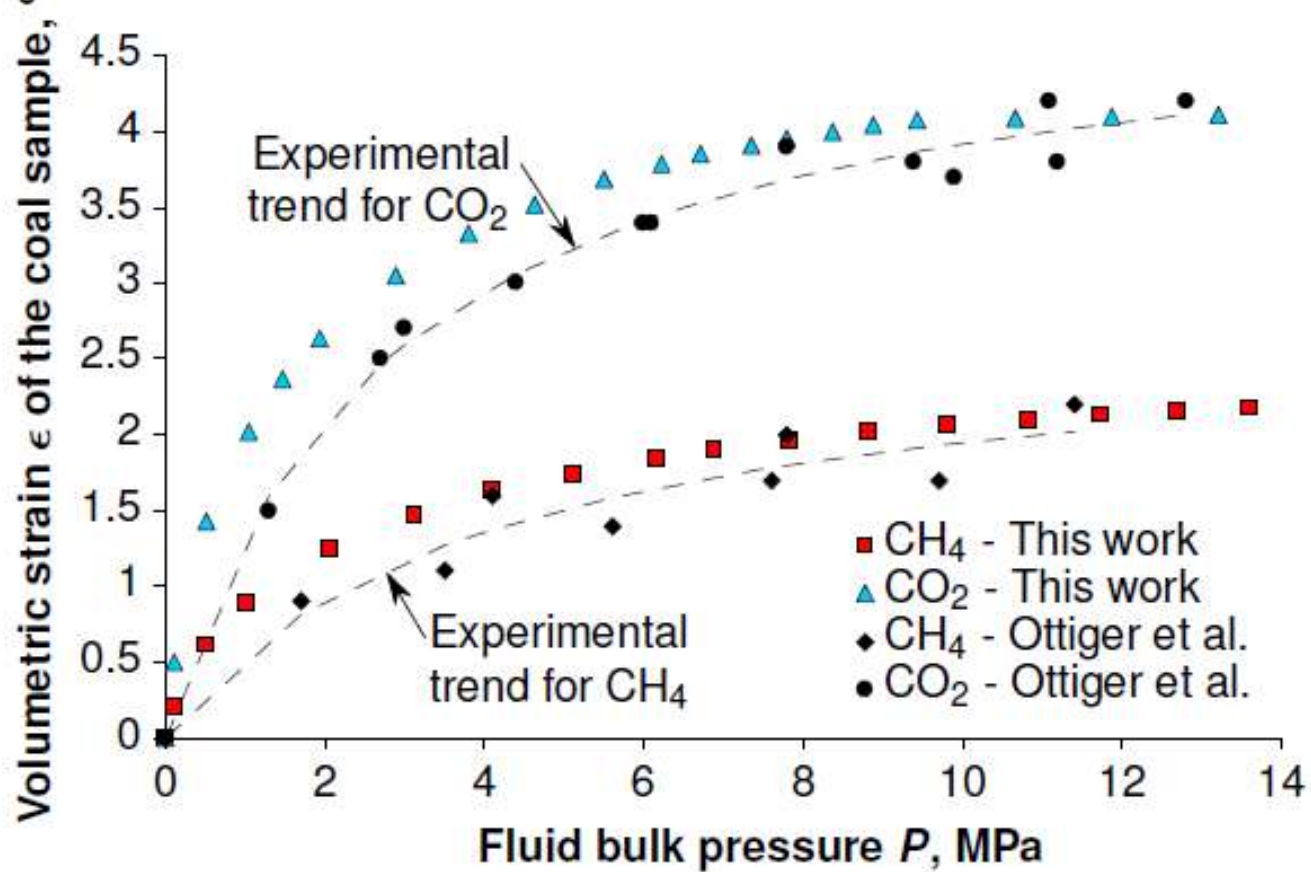
$$S_{ab} = 2\bar{G}e_{ab}$$

Laurent Brochard, Matthieu Vandamme, Teddy Fen-Chong, Olivier Coussy

Navier, ENPC-IFSTTAR-CNRS



$$\sigma = -P \Rightarrow \epsilon^u = -\frac{P}{K} + \frac{\tilde{C}}{K} \int_0^P \tilde{n}(\epsilon = 0) \bar{V}_{bulk} dP$$



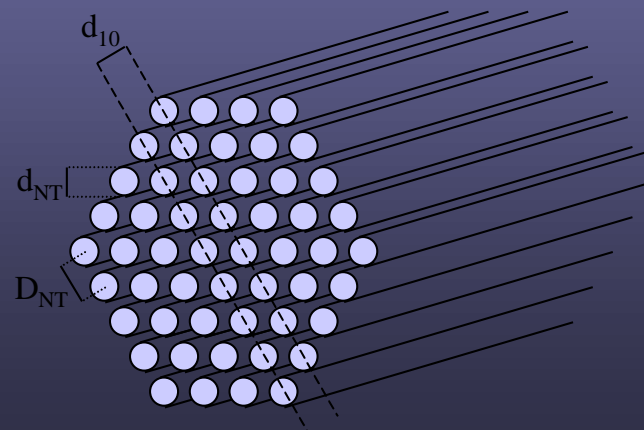
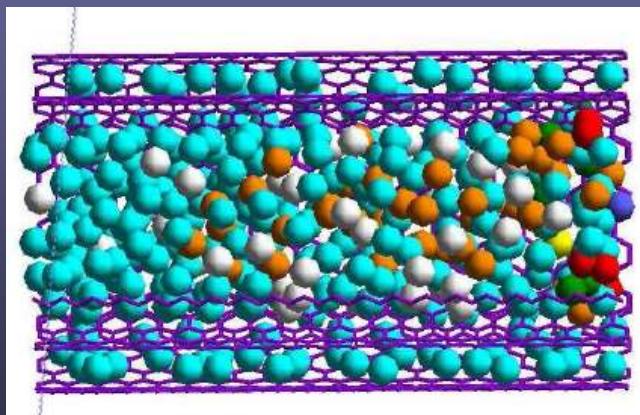
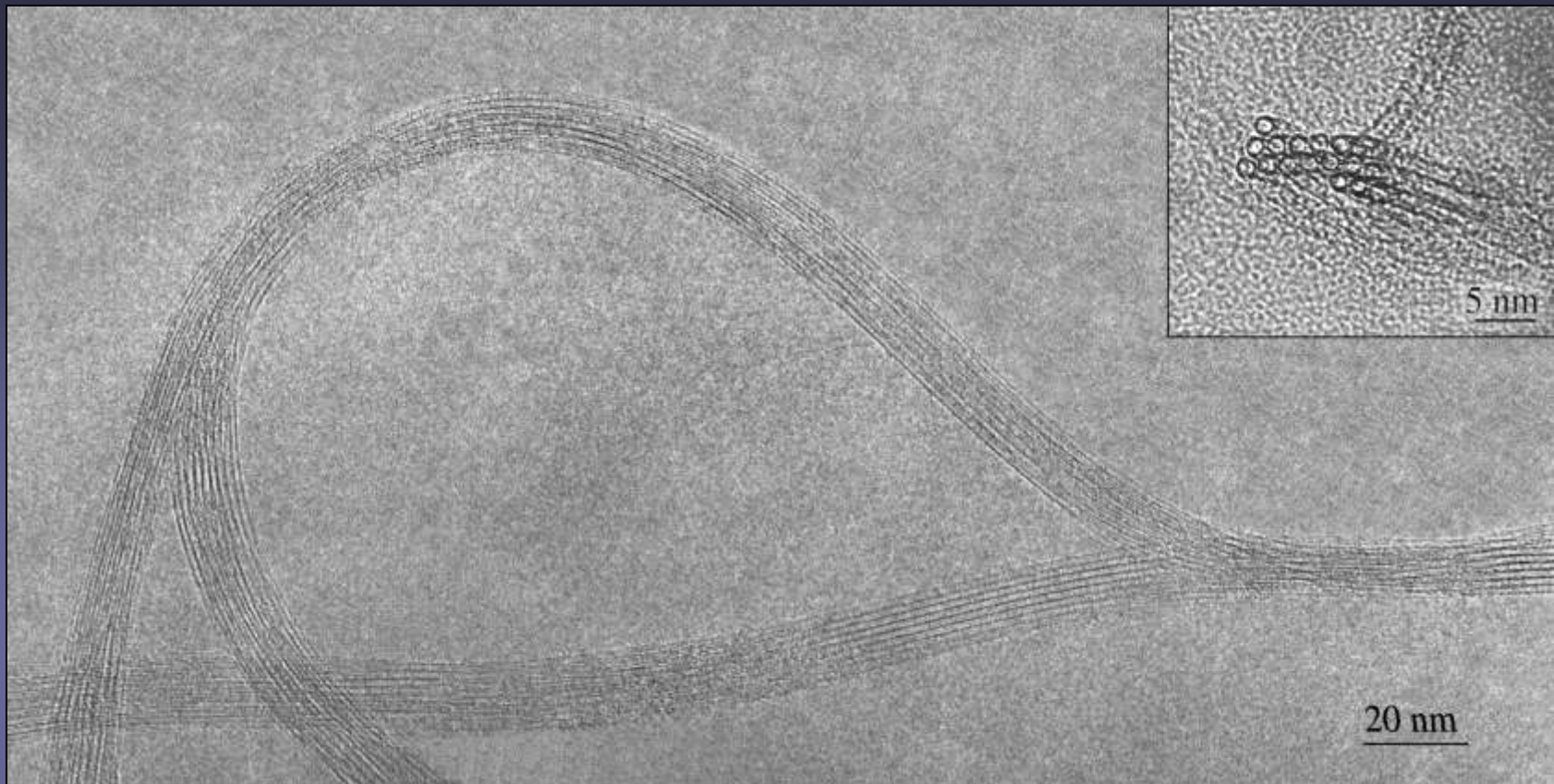
Laurent Brochard, Matthieu Vandamme, Teddy Fen-Chong

Navier, ENPC-IFSTTAR-CNRS

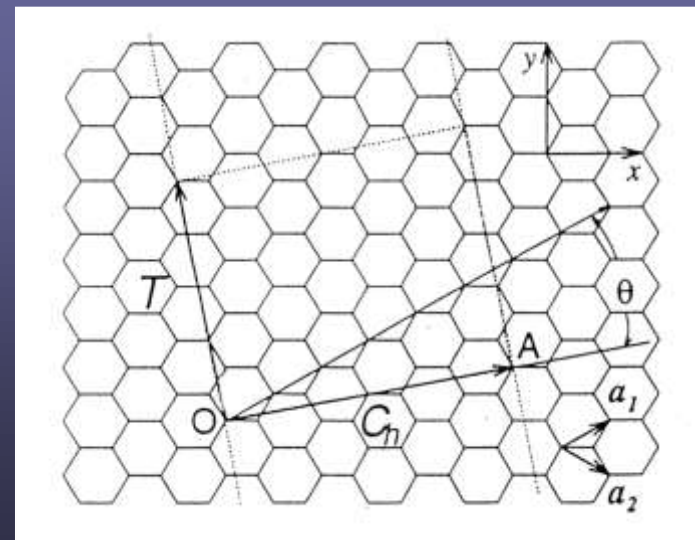
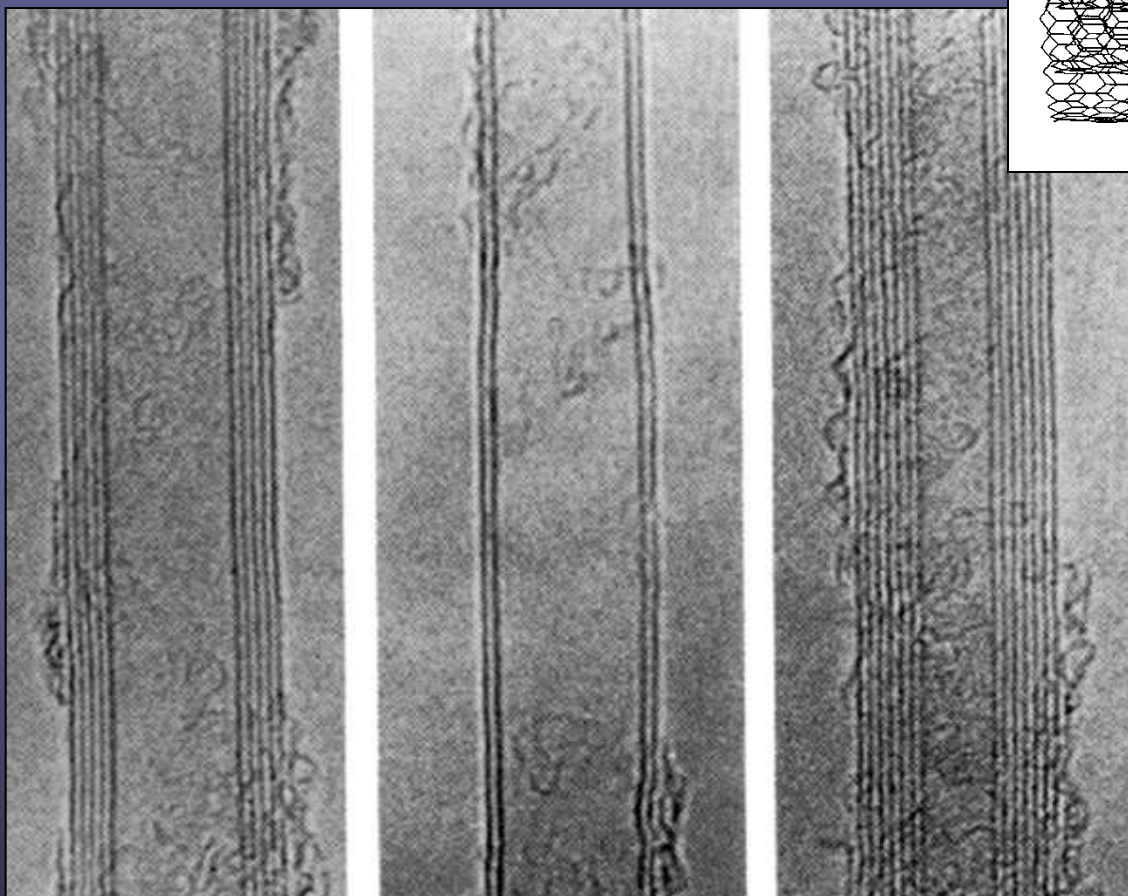
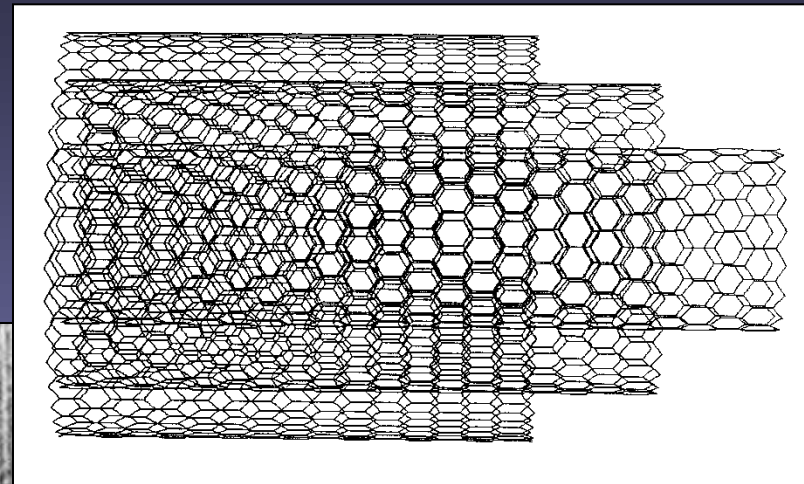


Vous avez dit « Darcy » ?

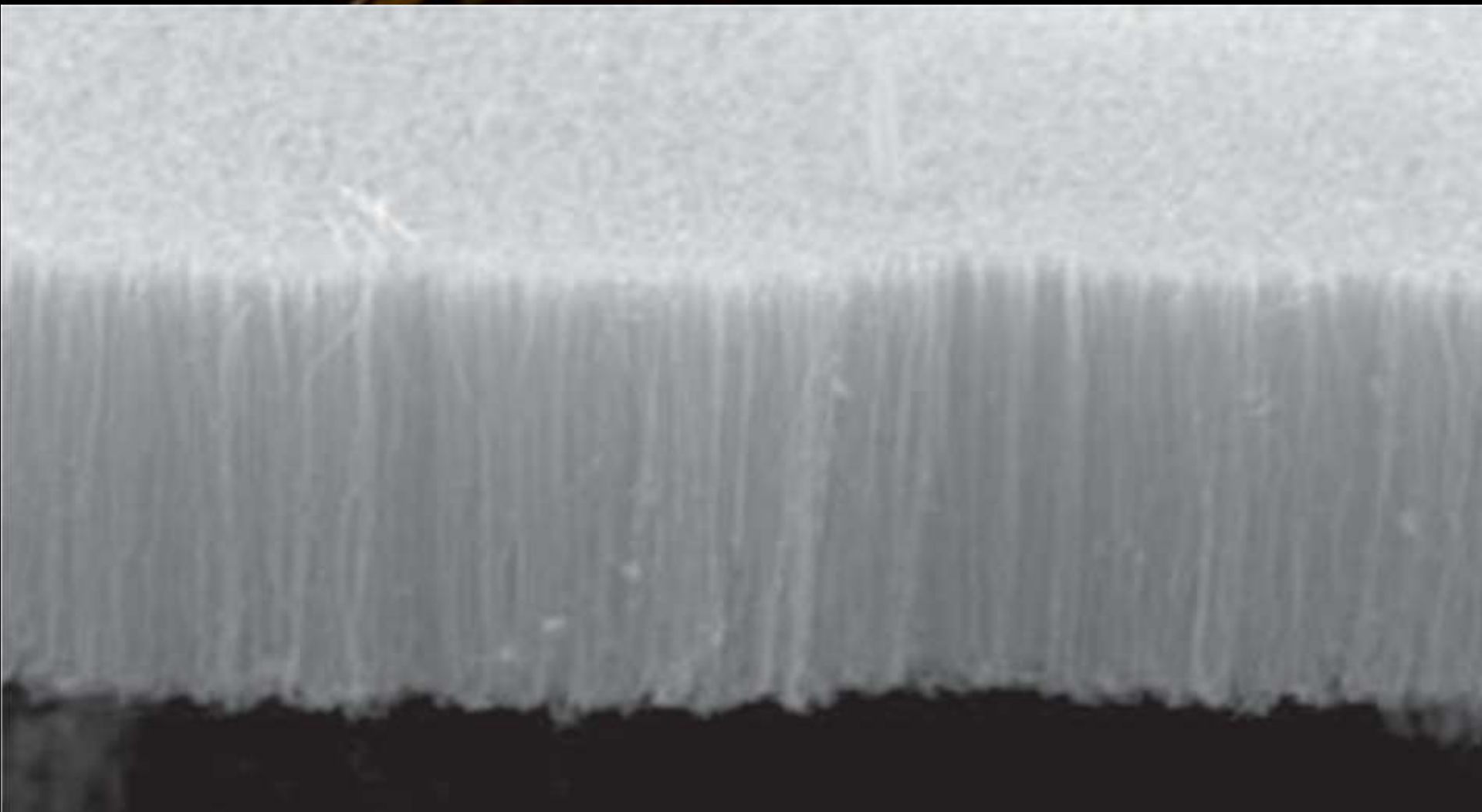




Simple- ou multi-parois (SWNT ou MWNT)

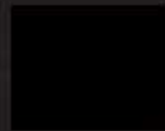


Membranes de nanotubes



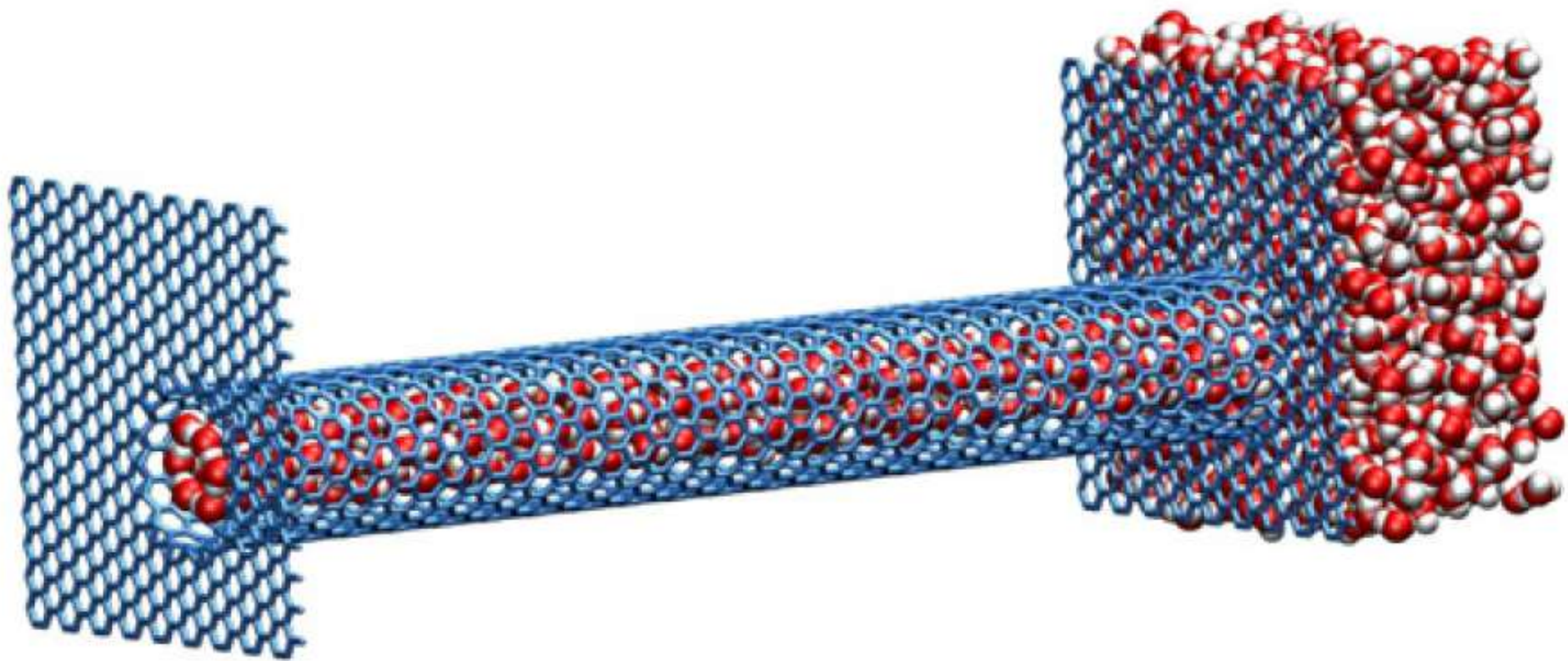
5 μm

Acc.V	Spot	Magn	Det	
15.0 kV	5.0	6000x	SE	Sample

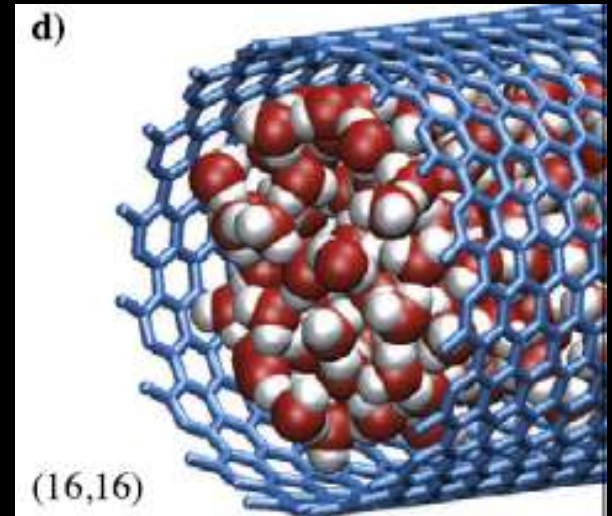
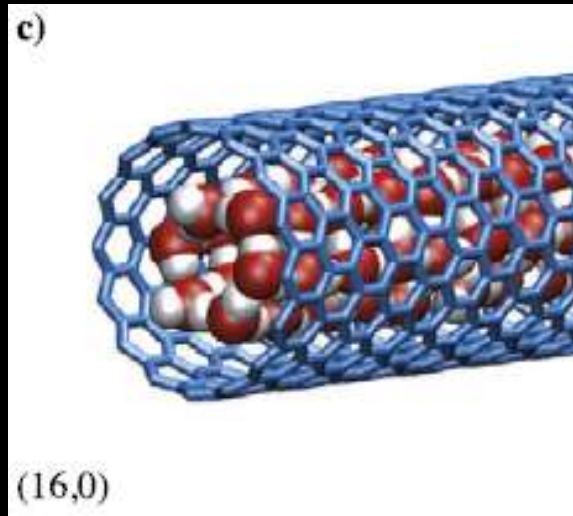
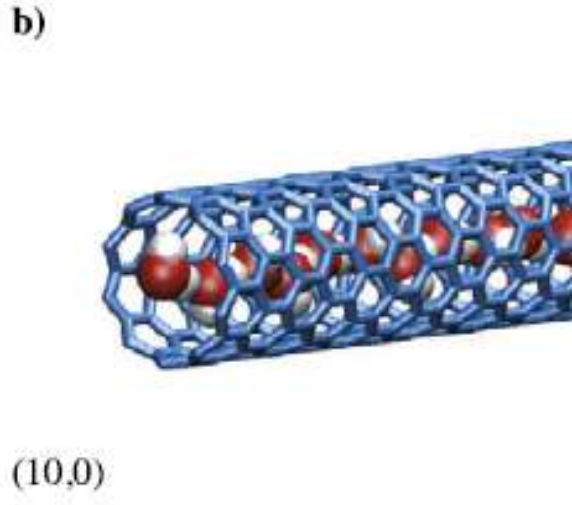


Theory and simulations of water flow through carbon nanotubes: prospects and pitfalls

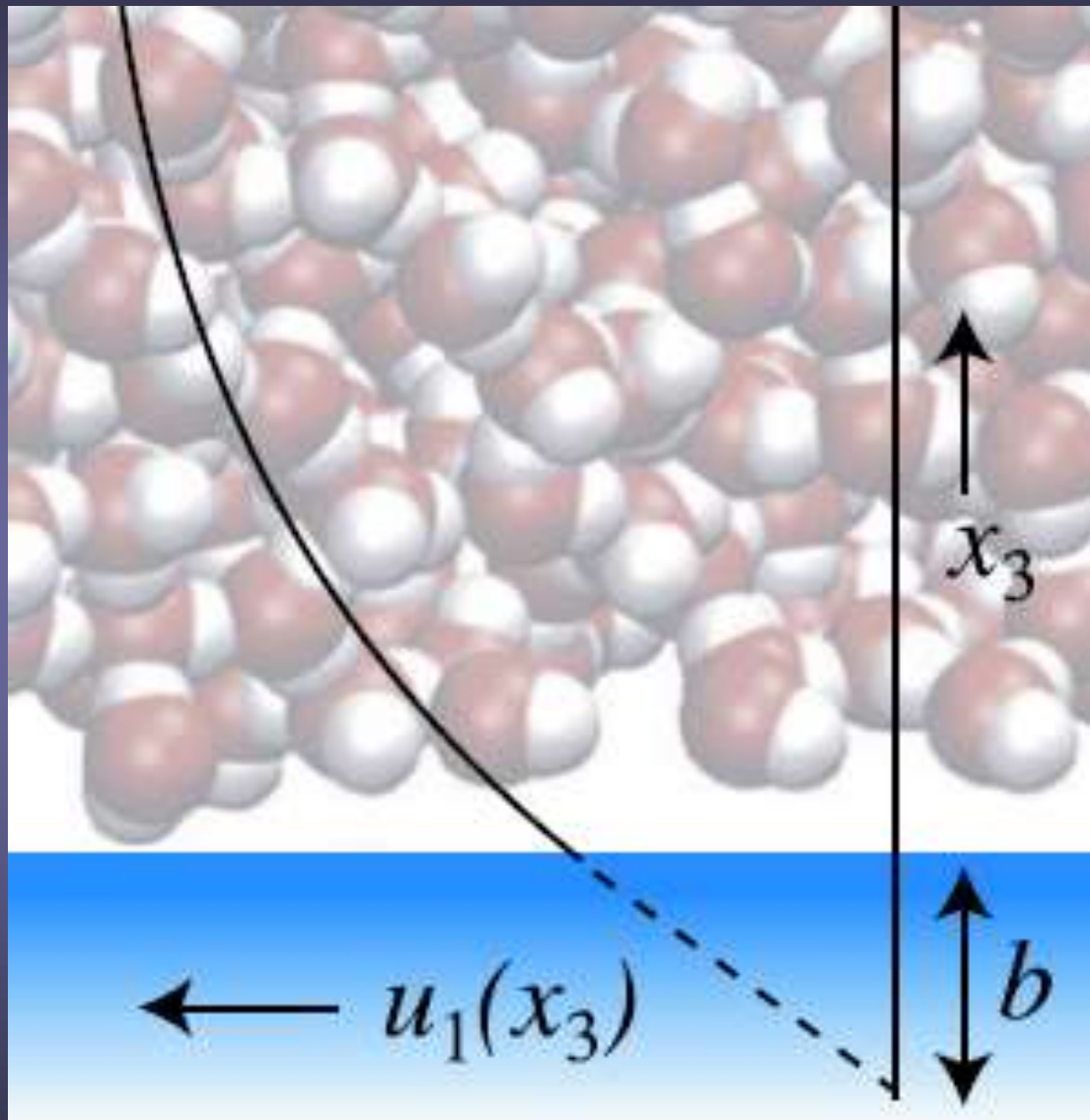
**Douwe Jan Bonthuis¹, Klaus F Rinne¹, Kerstin Falk²,
C Nadir Kaplan^{1,3}, Dominik Horinek¹, A Nihat Berker^{1,4},
Lydéric Bocquet^{1,2} and Roland R Netz¹**



D.J. Bonthuis et al., 2011



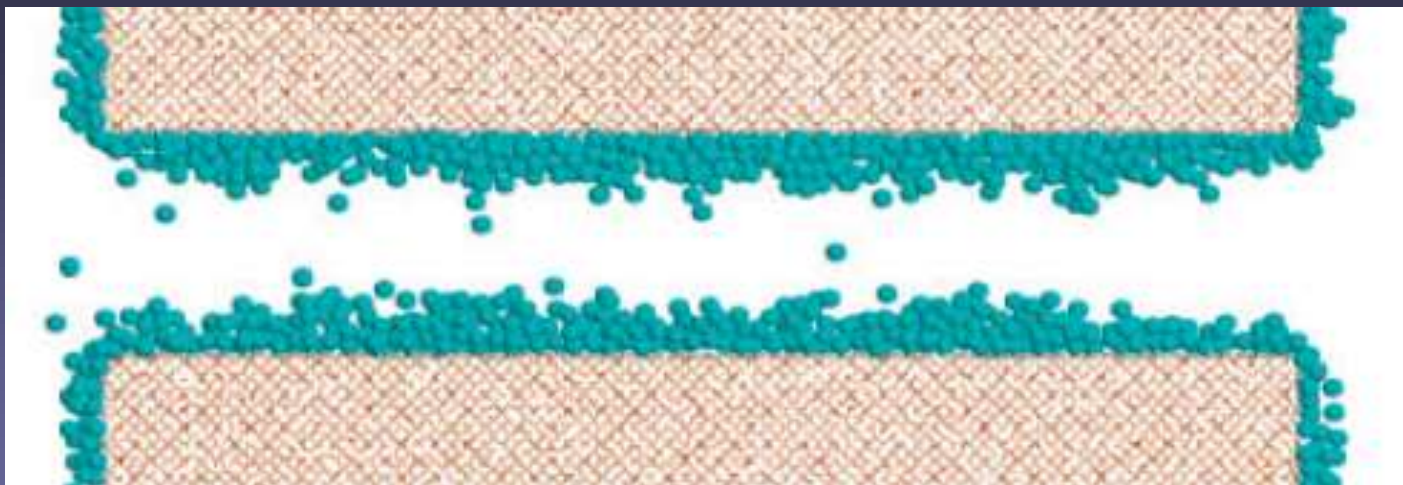
D.J. Bonthuis et al., 2011





Vous avez dit « condensation » ?



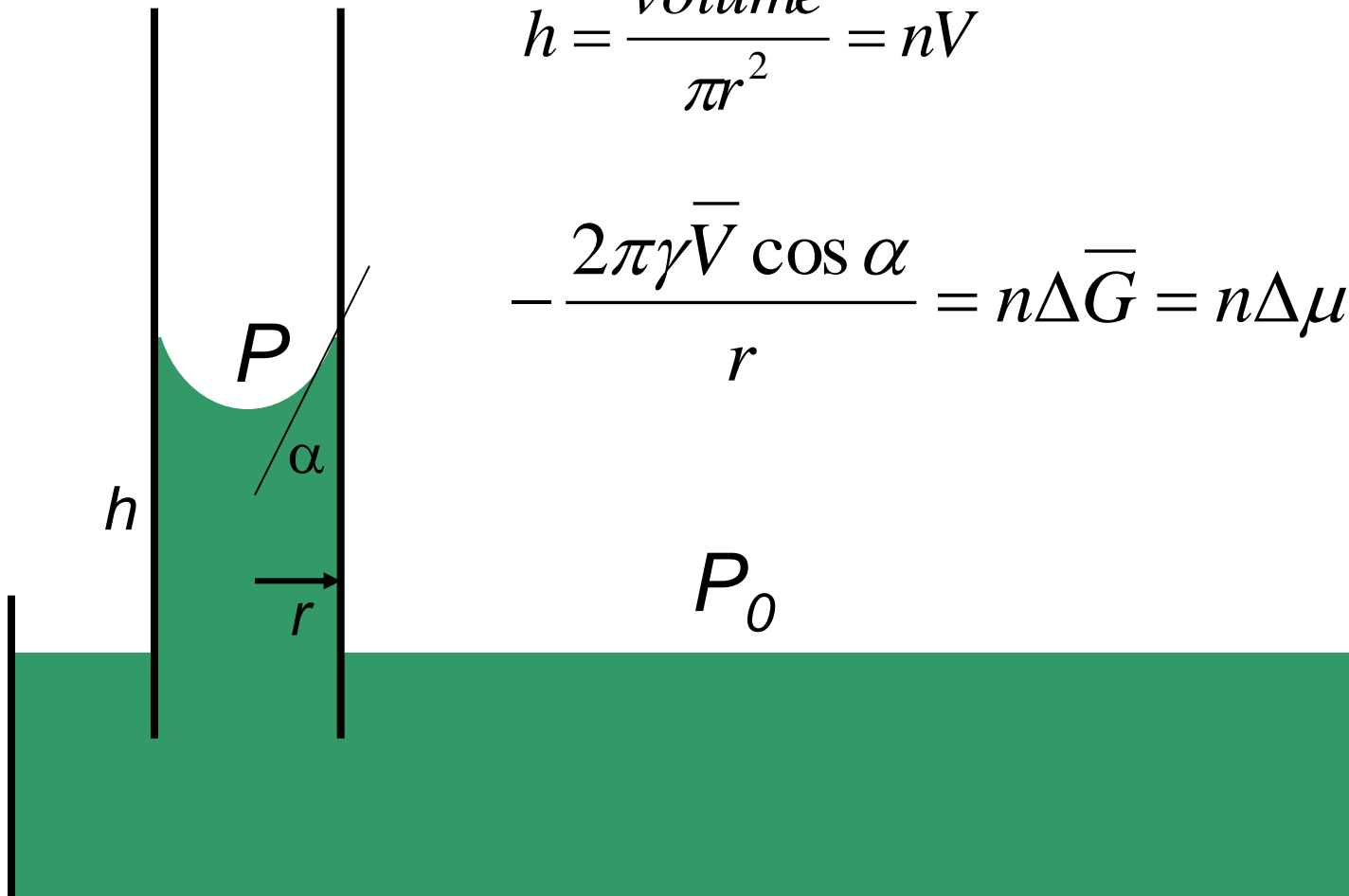


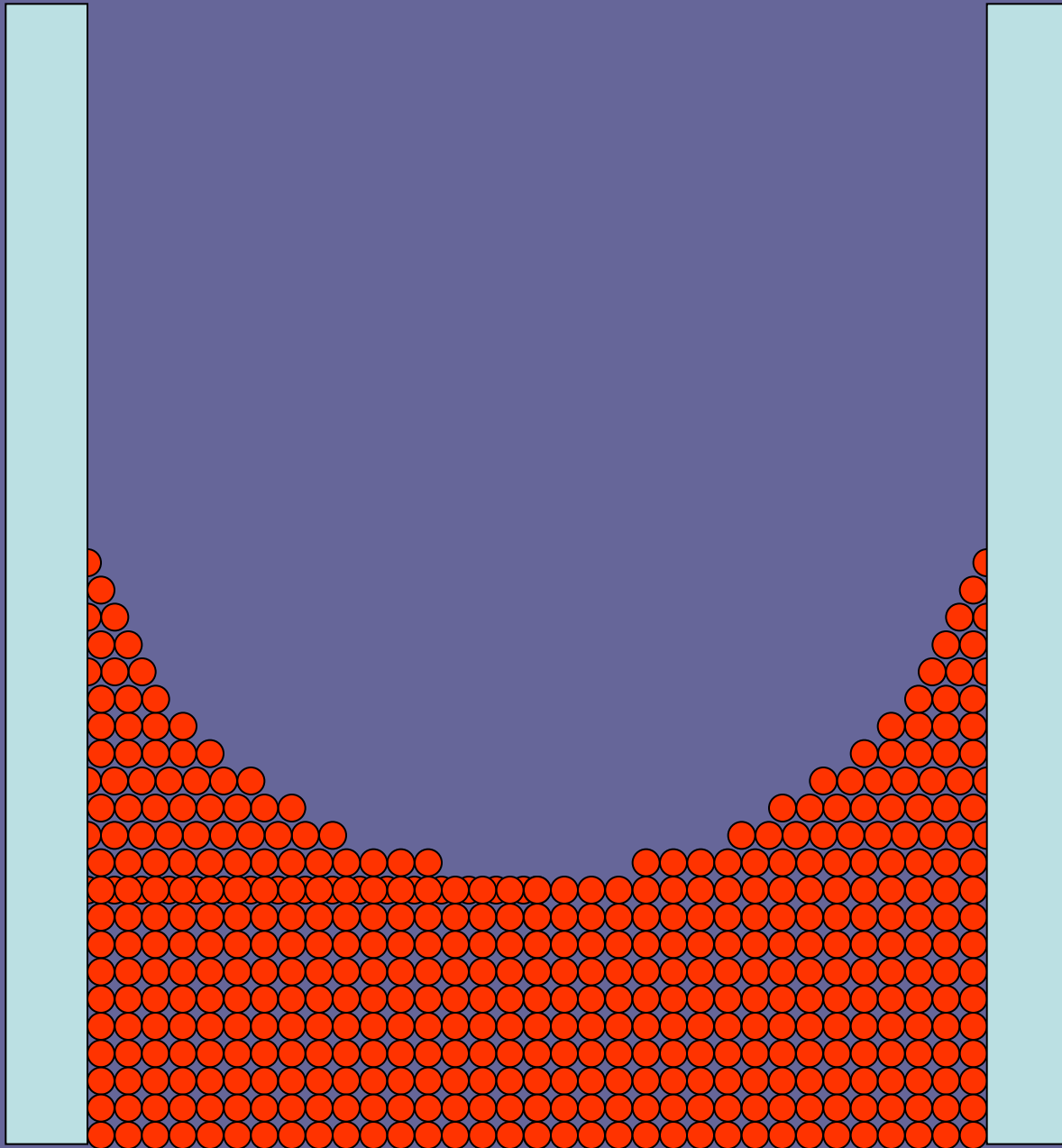
B. Coasne et al., *Chem. Soc. Rev.* (2013) 42, 4141 - 4171

$$-\int_0^h 2\pi r \gamma \cos \alpha dh = -2\pi r \gamma h \cos \alpha$$

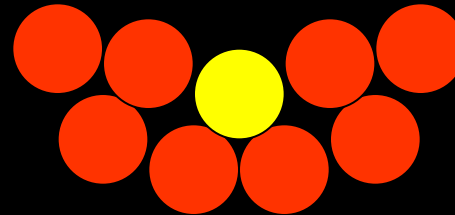
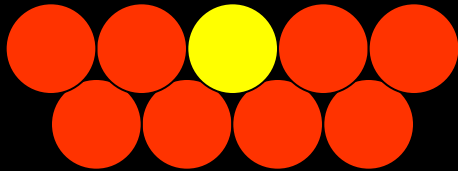
$$h = \frac{\text{volume}}{\pi r^2} = n\bar{V}$$

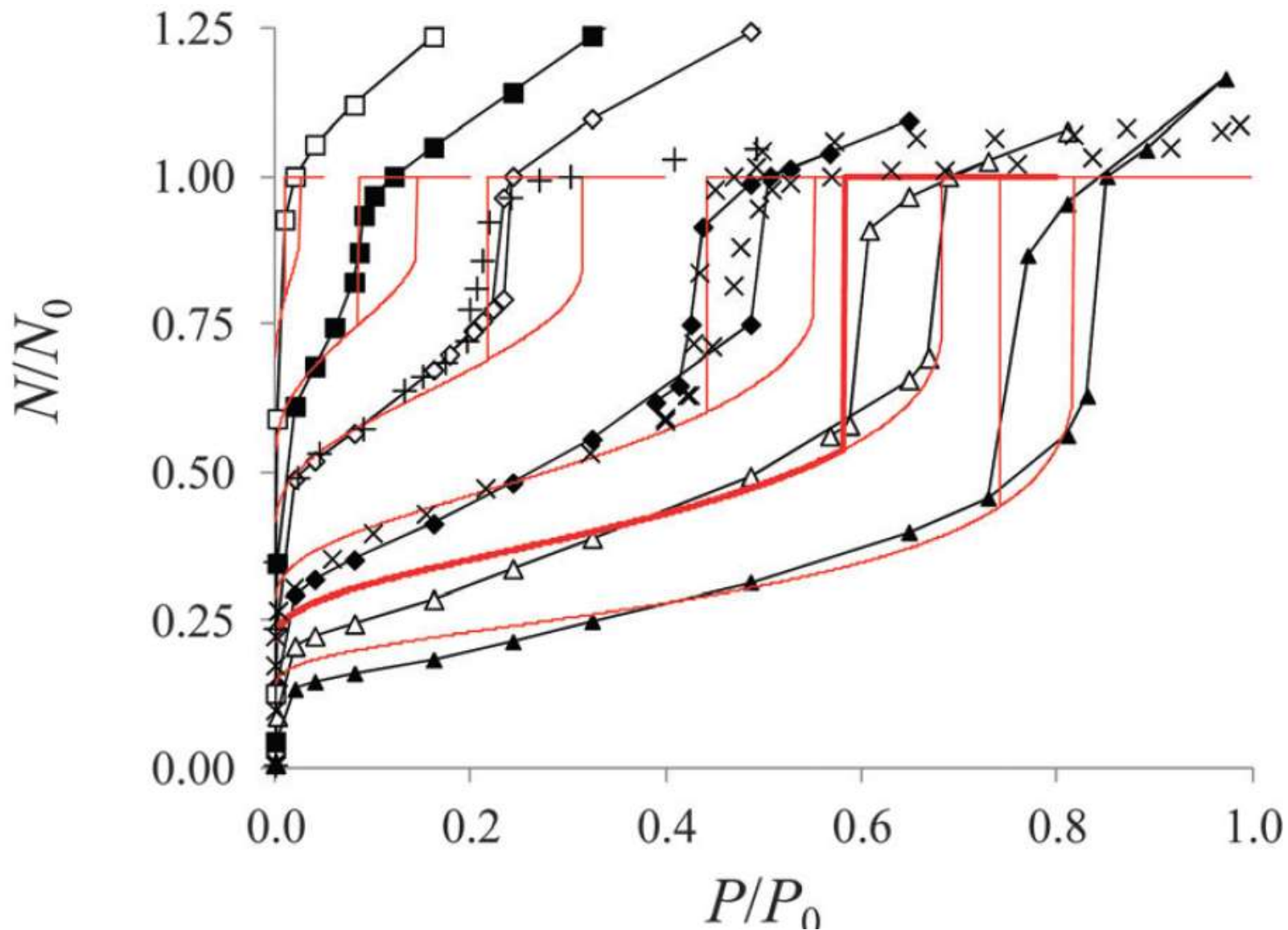
$$-\frac{2\pi\gamma\bar{V} \cos \alpha}{r} = n\Delta\bar{G} = n\Delta\mu$$



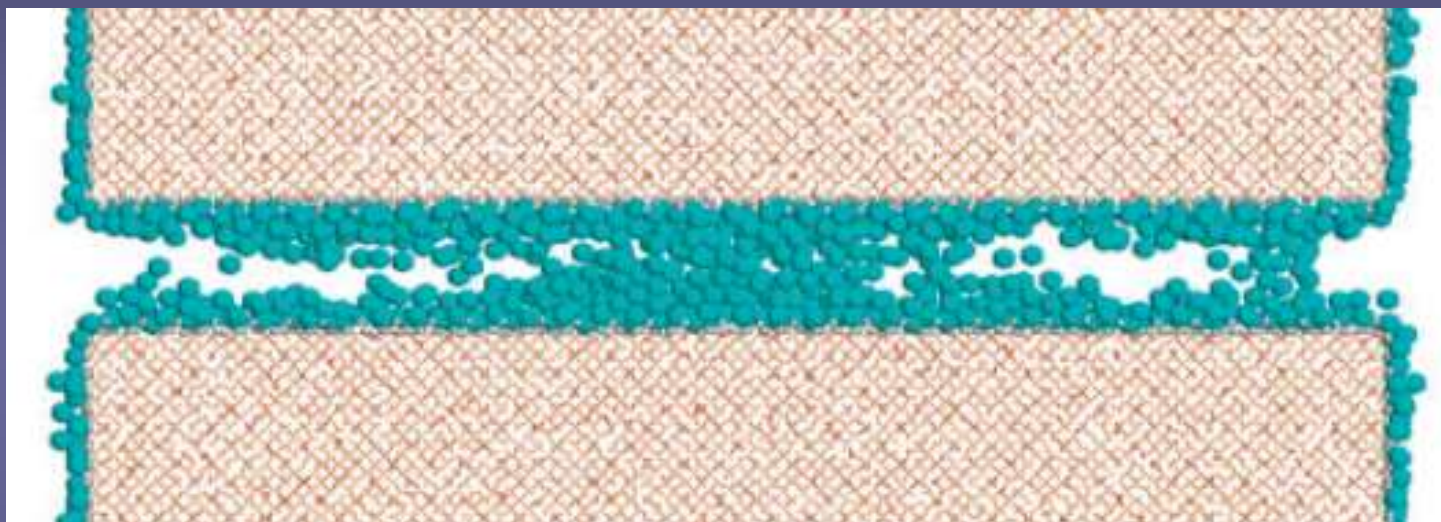


C'est la courbure qui compte !

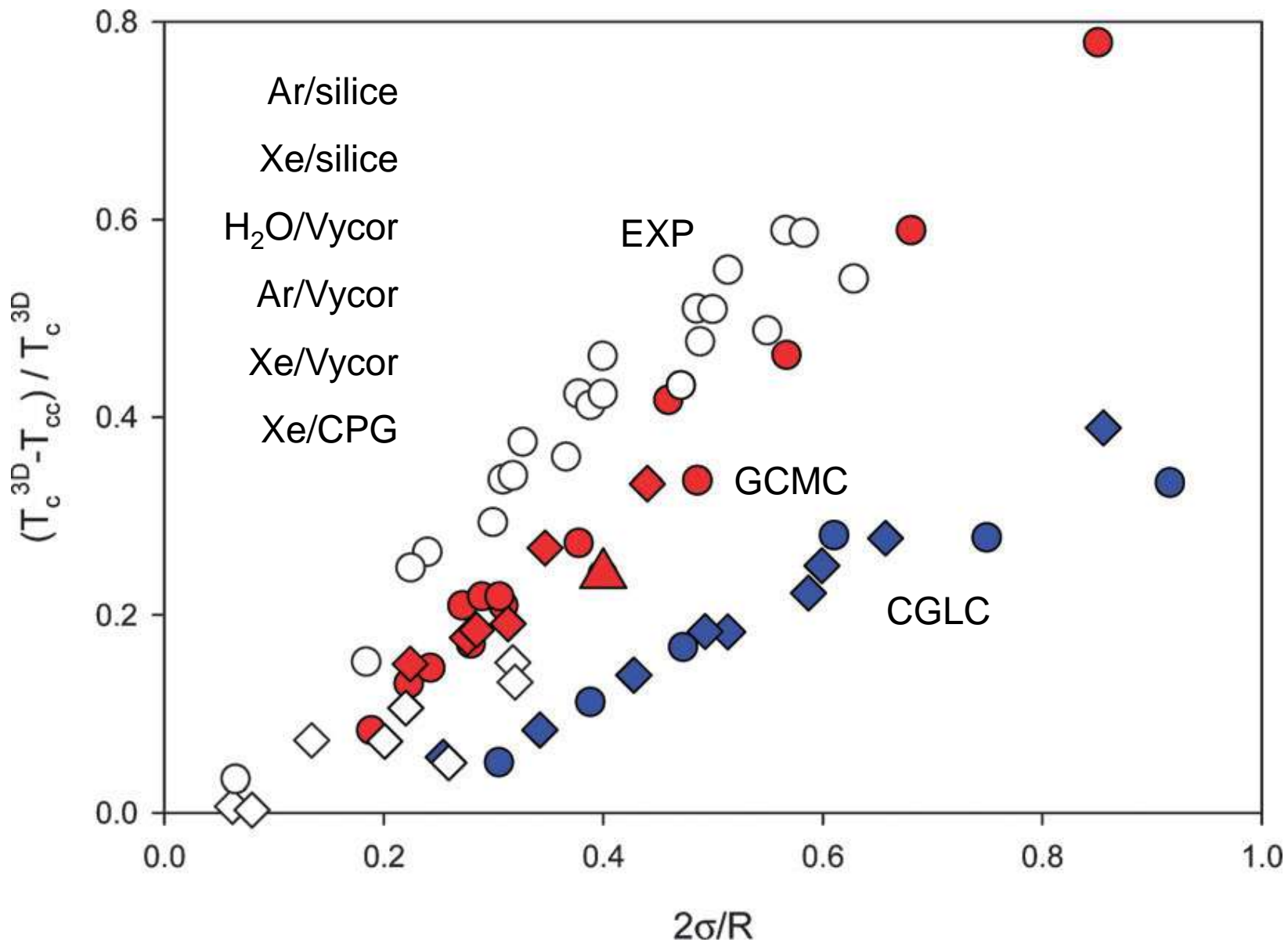




B. Coasne et al., Chem. Soc. Rev. (2013) 42, 4141 - 4171



B. Coasne et al., Chem. Soc. Rev. (2013) 42, 4141 - 4171



Isolez, isolez...

$$\Phi = - \lambda \frac{\Delta T}{\Delta z}$$

$(J / m^2 \cdot s)$

$(^\circ / m)$

$W / ^\circ \cdot m$

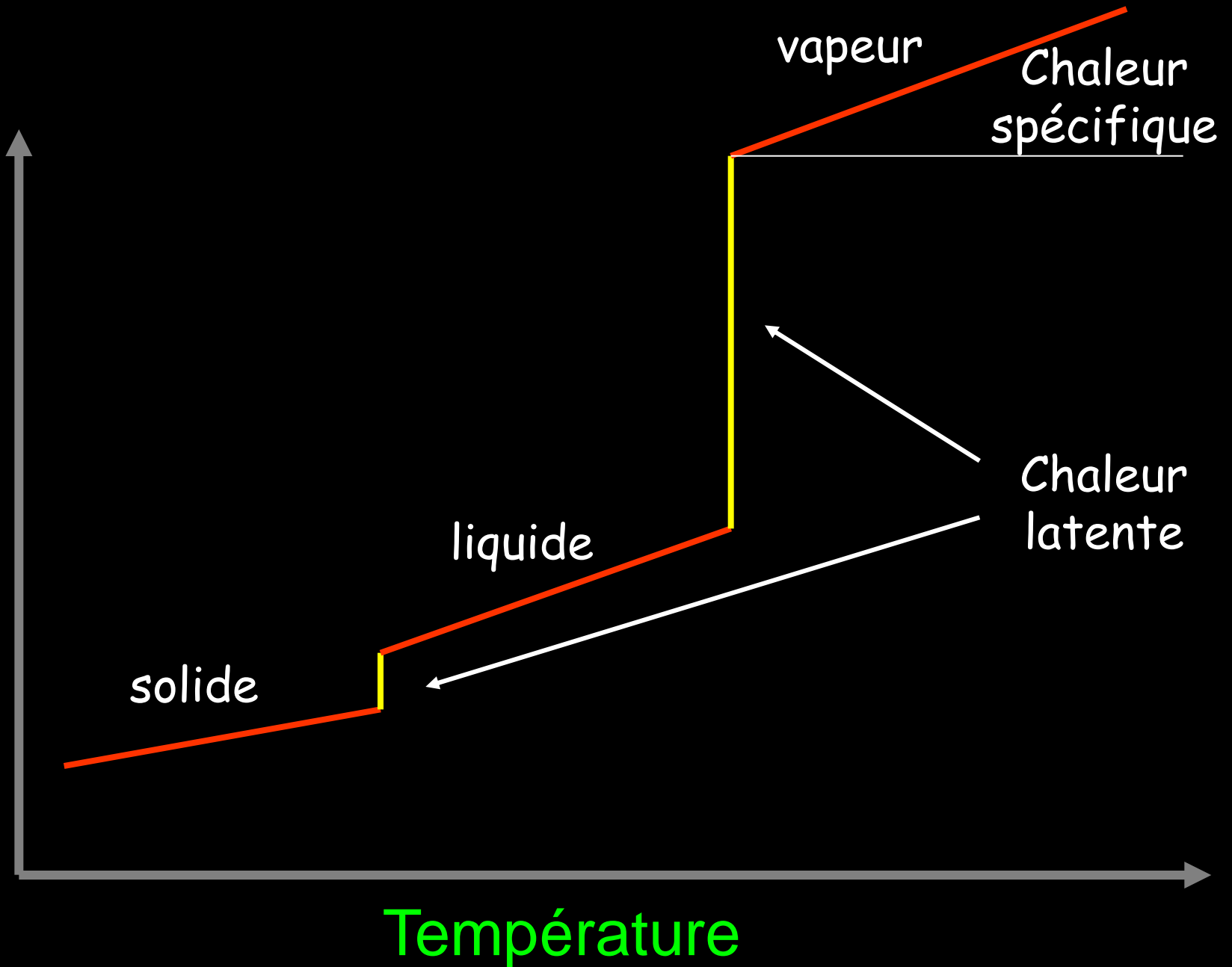
Romain Anger

λ

La diffusivité thermique permet d'évaluer la capacité d'un matériau à transmettre une onde thermique:

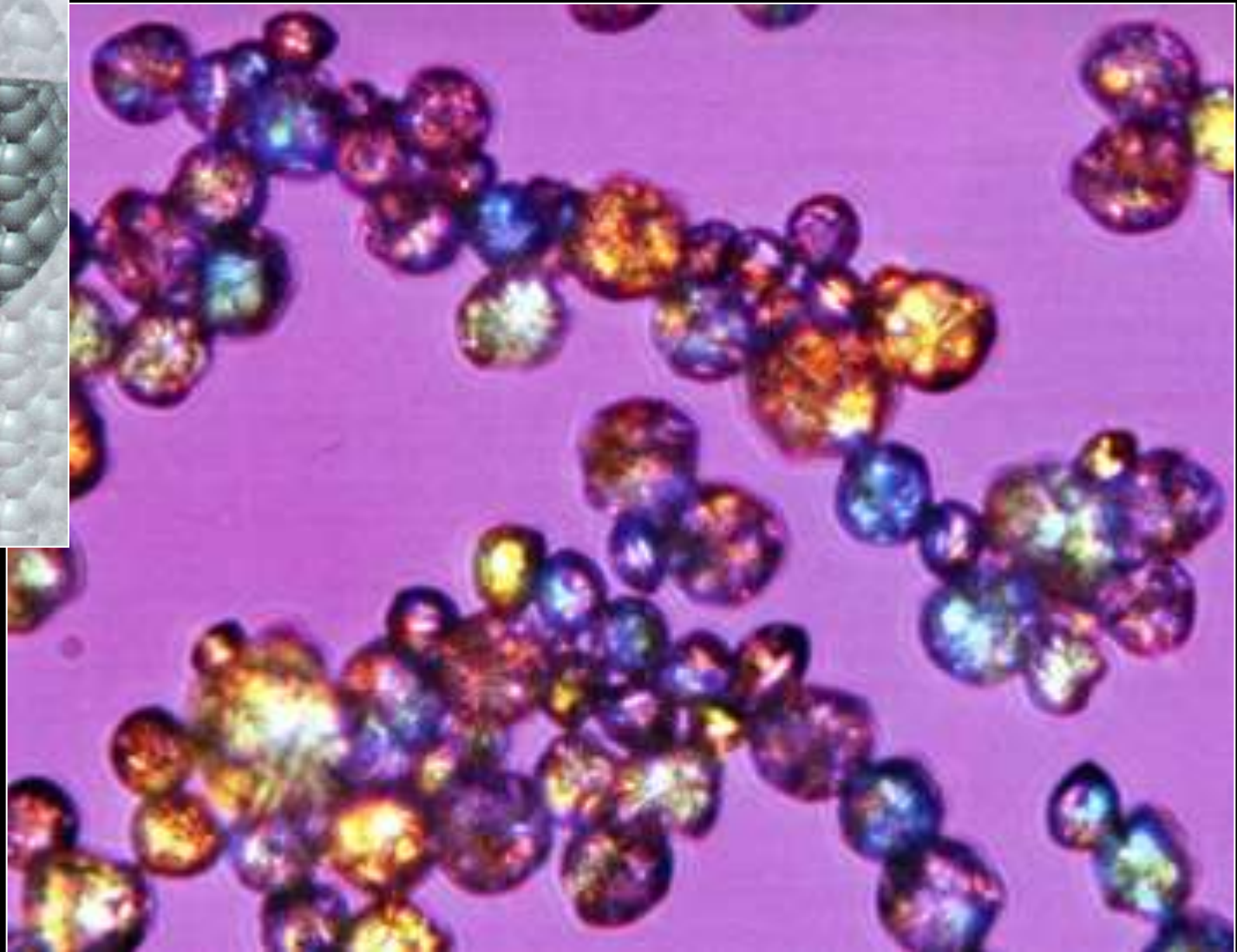
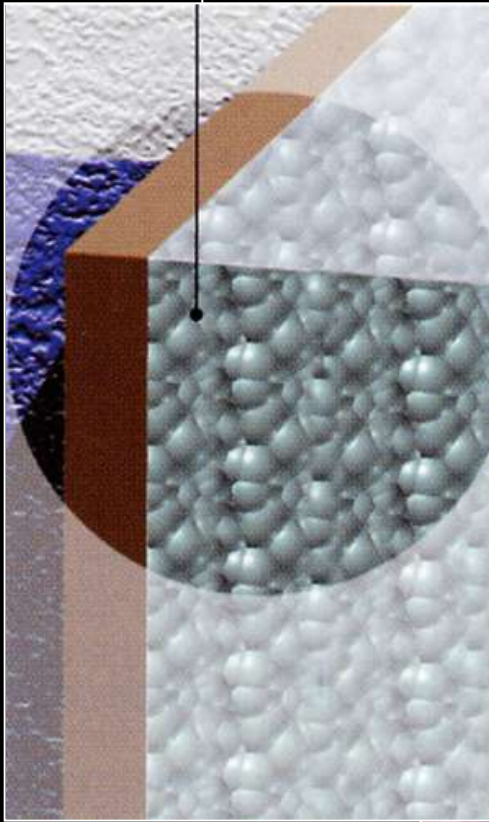
$$Diff = \frac{\lambda}{\rho \cdot C_p}$$

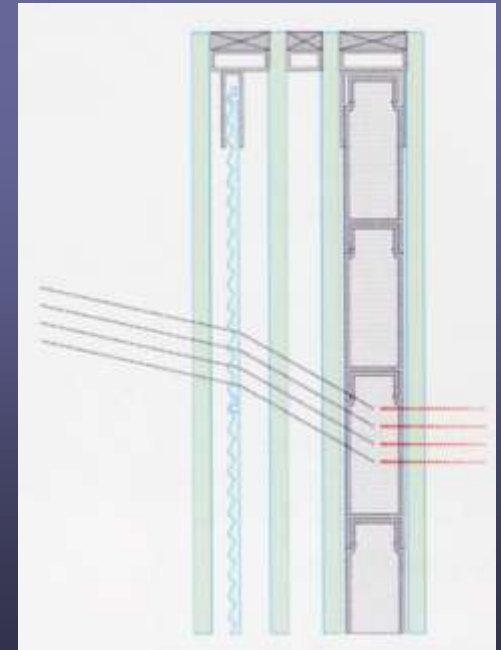
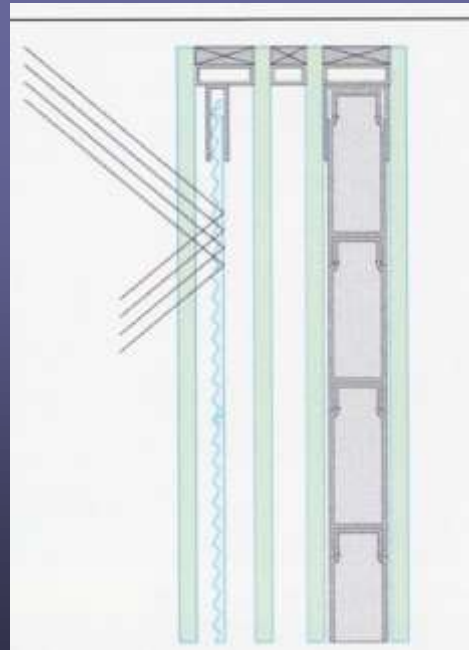
H
Quantité de chaleur



Billes de paraffine

Un peu plus que l'isolation...





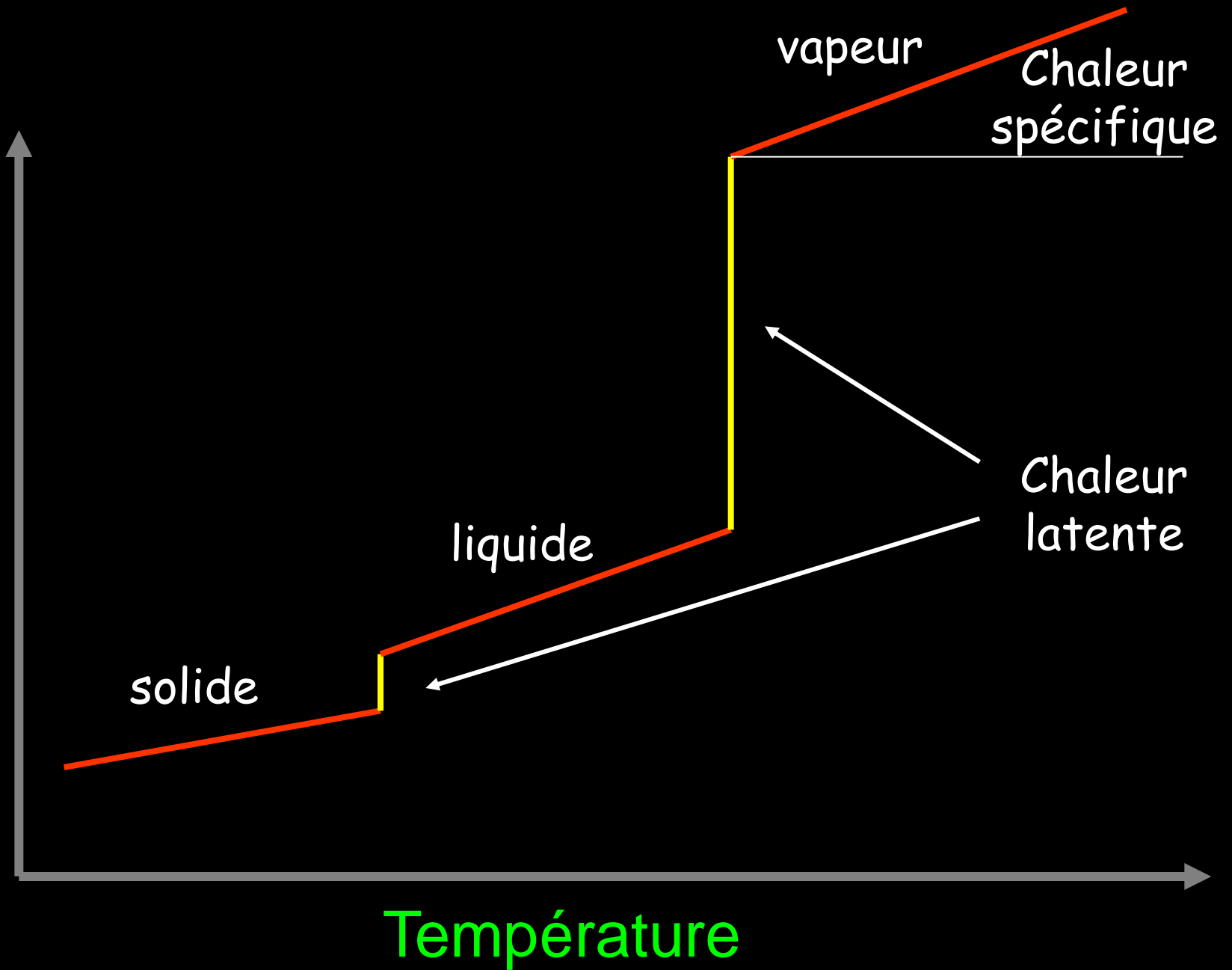
Senior citizen's apartments, Ebnat-Kappel, CH



Dietrich Schwarz, architect



H
Quantité de chaleur



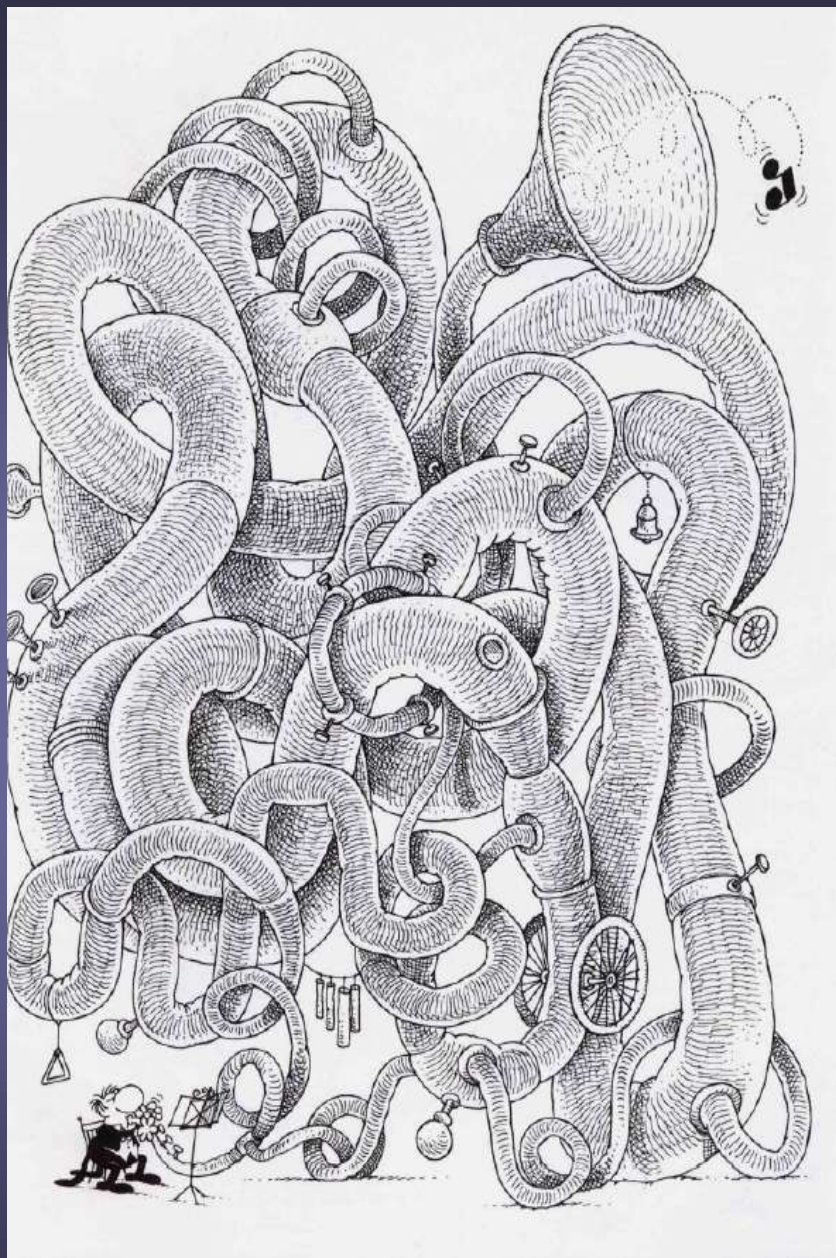






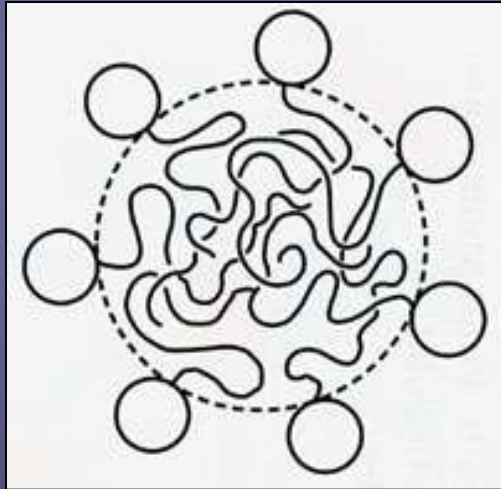
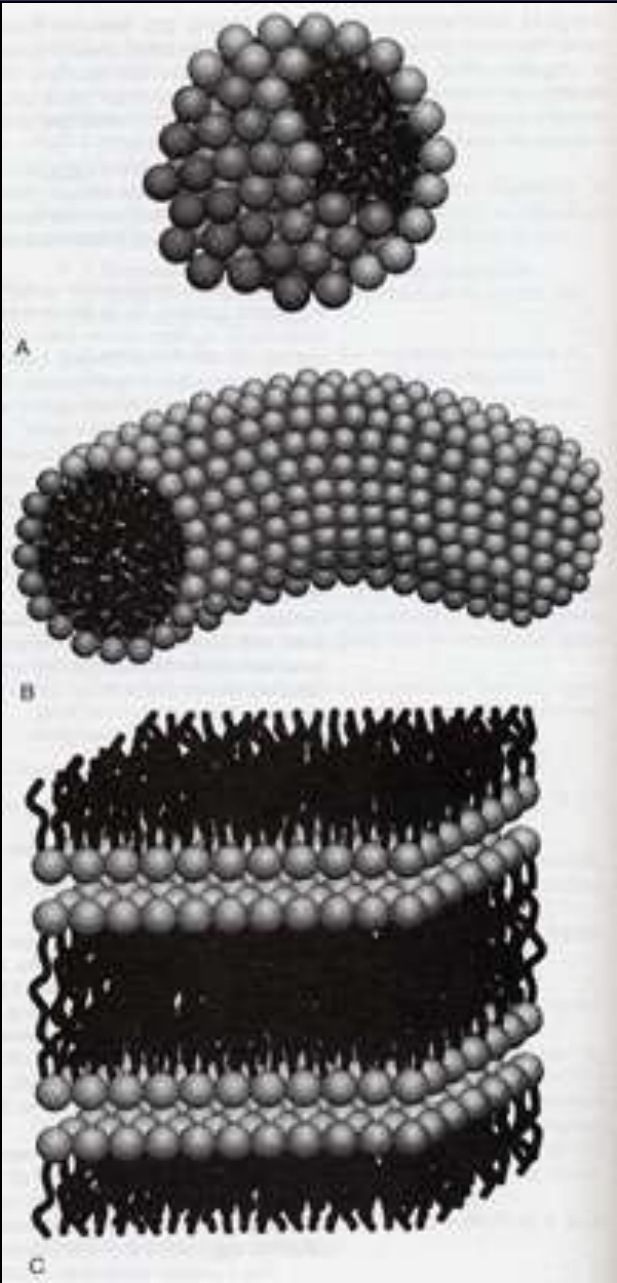


Où est la sortie?

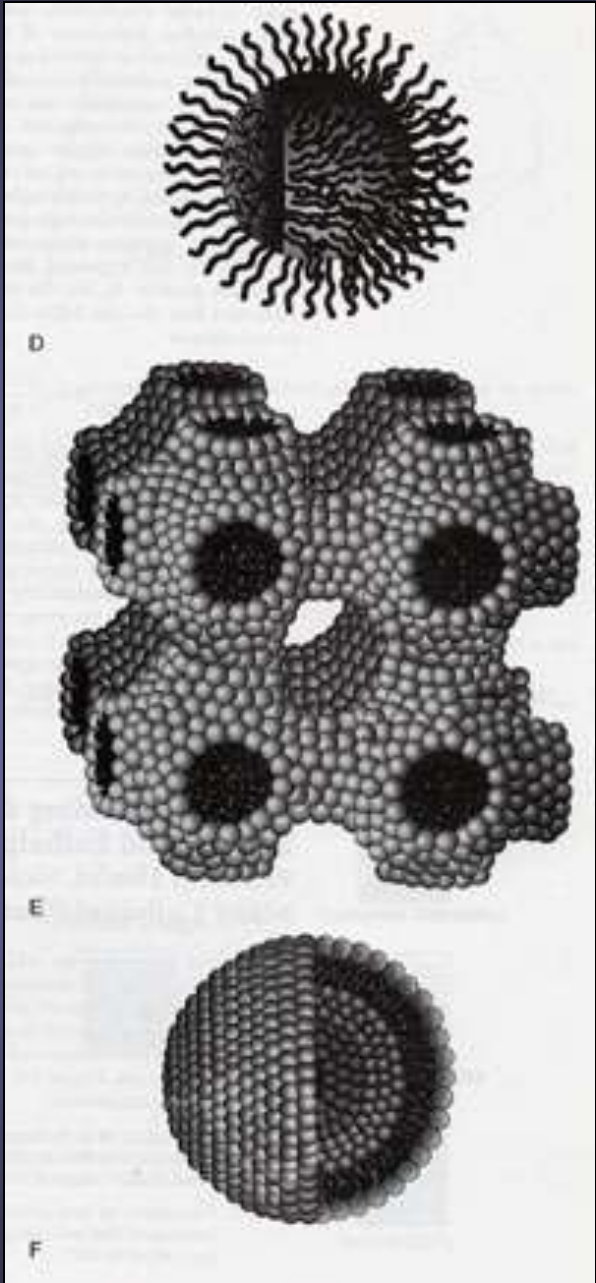


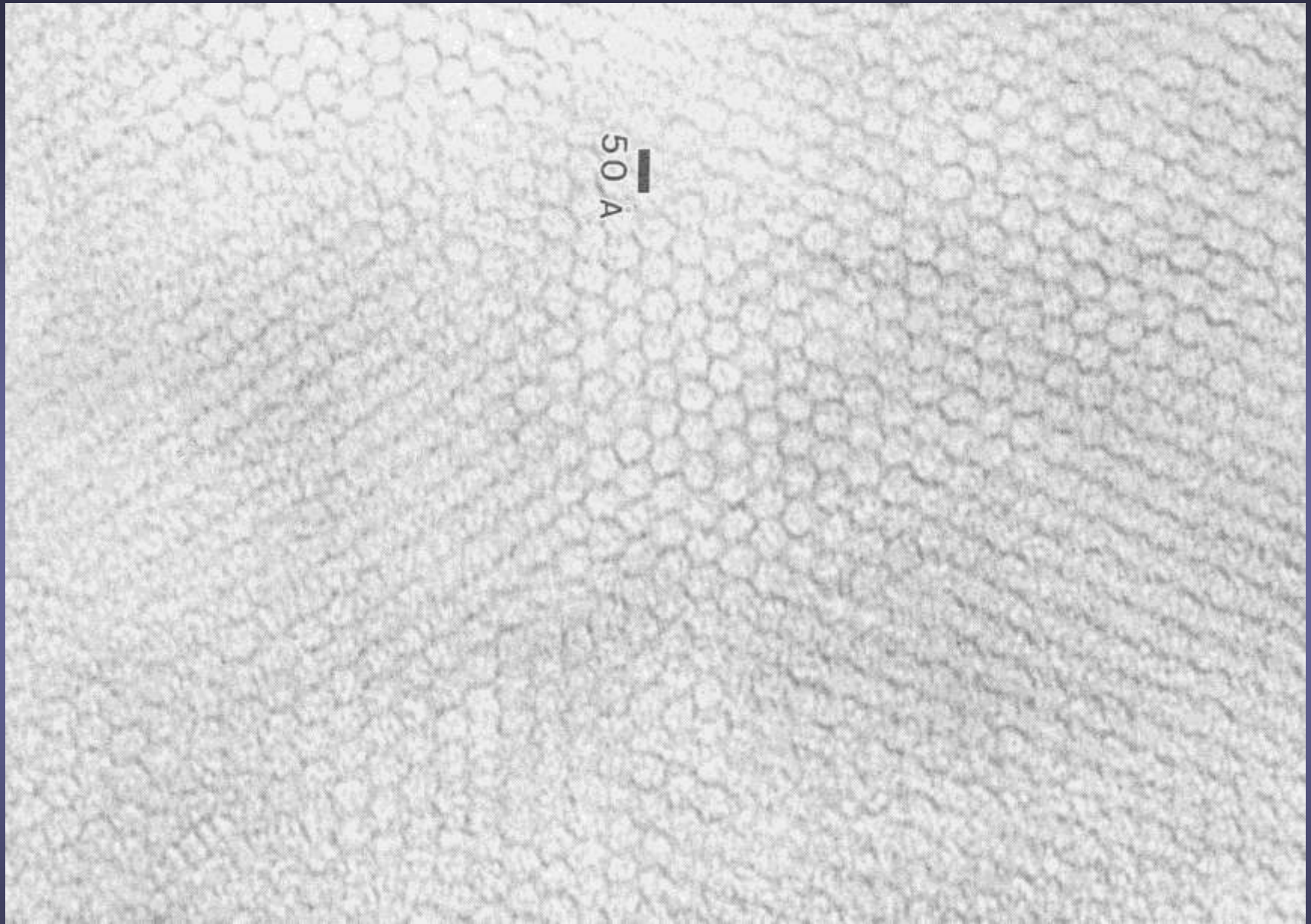
Un long chemin tortueux...

**Des SMO simples:
les assemblés
micellaires**



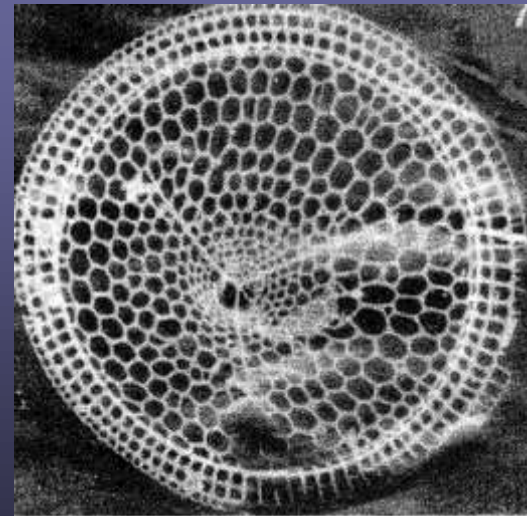
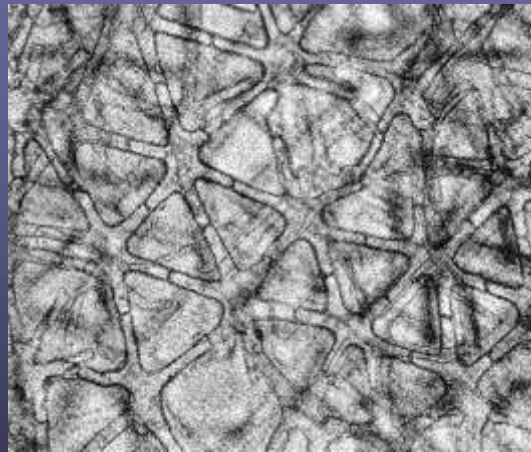
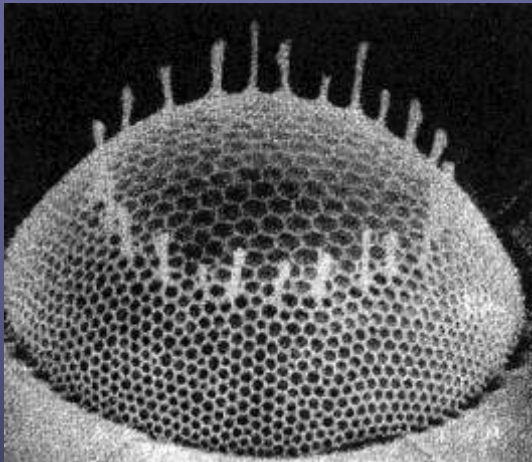
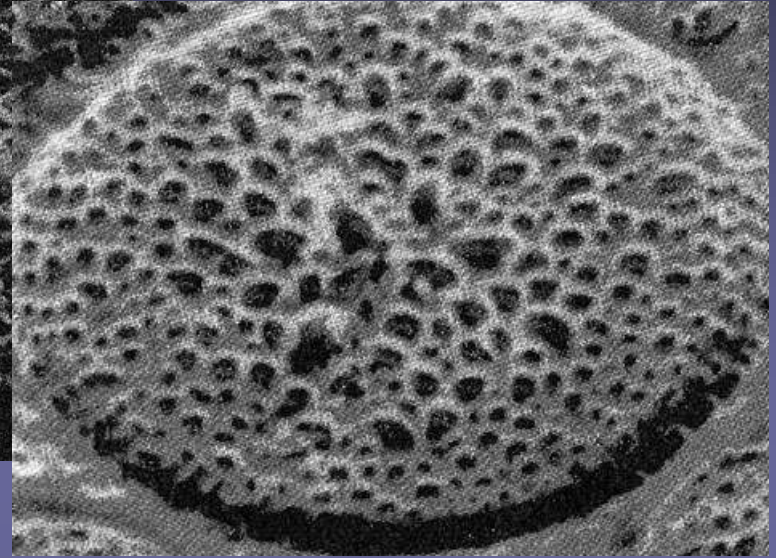
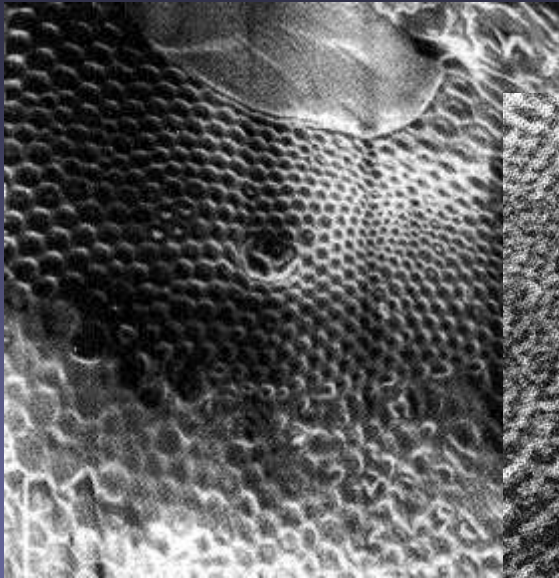
**D. Evans & H.
Wennerström
Wiley**





C.T. KRESGE et al. (MOBIL), *NATURE* (1992)

Vrais et faux exosquelettes... (aluminophosphates)



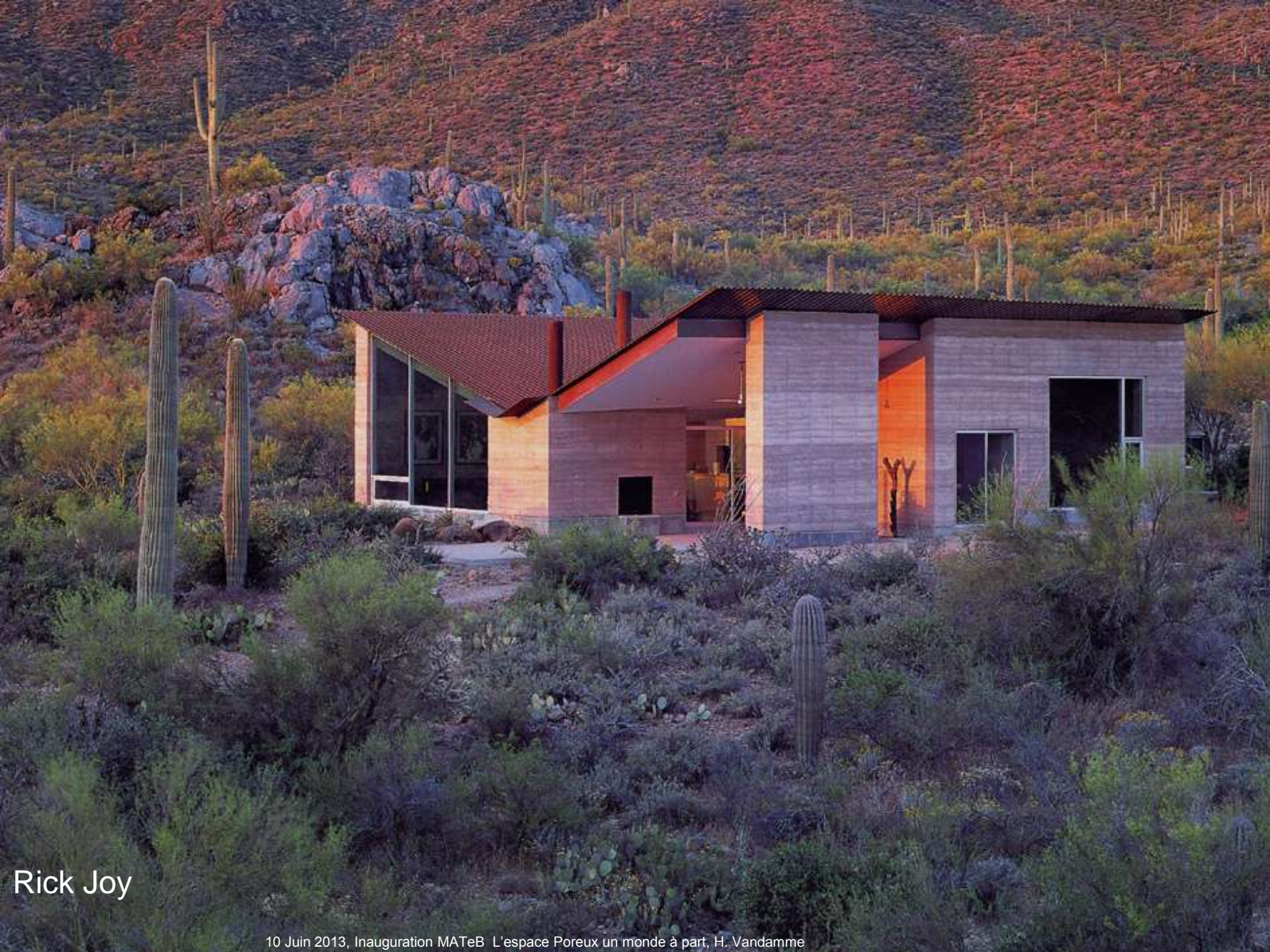
Nature, 1995

G. Ozin et al., U. Toronto



Shibam, Built by Hand

10 Juin 2013, Inauguration MATeB L'espace Poreux un monde à part, H. Vandamme



Rick Joy

10 Juin 2013, Inauguration MATeB L'espace Poreux un monde à part, H. Vandamme



Merci pour votre attention

